Design and assessment of ergonomic seat in planes

FINAL DEGREE PROJECT

BACHELOR’S DEGREE IN INDUSTRIAL TECHNOLOGIES

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LIST OF ABBREVIATIONS

CAA	(Civil Aviation Authority)
CCOHS	(Canadian Centre for Occupational Health and Safety)
DGT	(Dirección General de Tráfico)
DVT	(Deep Vein Thrombosis)
EASA	(European Aviation Safety Agency)
EU	(European Union)
FMEA	(Failure Modes and Effects Analysis)
IASP	(International Association for the Study of Pain)
IATA	(International Air Transport Association)
IBV	(Instituto Biomecánico de Valencia)
IEA	(International Ergonomic Association)
IEHF	(Institute of Ergonomics and Human Factors)
IHI	(Institute of Healthcare Improvement)
INSHT	(Instituto Nacional de Seguridad e Higiene en el Trabajo)
LUBA	(Loading on the Upper Body Assessment)
MMC	(Manipulación Manual de Cargas)
MMGA	(Method for Movement and Gesture Assessment)
MSDs	(Musculoskeletal Disorders)
NIOSH	(National Institute for Occupational Safety and Health)
OSHA	(Occupational Safety and Health Administration)
OWAS	(Ovako Working Analysis System)
PPE	(Personal Protective Equipment)
REBA	(Rapid Entire Body Assessment)
RPKs	(Revenue Passenger Kilometers)
RPN	(Risk-priority-number)

RULA	(Rapid Upper Limb Assessment)
UNECE	(United Nations Economic Commission for Europe)
WHO	(World Health Organization)
WMSDs	(Work-related Musculoskeletal Disorders)
XWB	(Extra Wide Body)
3DSSPP	(3D Static Strength Prediction Program)

CHAPTER 1: ACKNOWLEDGES

I would like to express my sincere gratitude in these lines to people who have helped and supported me during the execution and overcoming of my university experience. This academic stage has lasted a period of five years, last of them have been combined with my first professional opportunity, which has taken place in the aerospace industry. In this way, during this academic year it has been completed a trainee program in the sector previously mentioned, and the aim of this fifth university year has also been the realization of this bachelor thesis. The completion of this bachelor thesis supposes the culmination of this educational stage, and I am completely sure difficulties and challenges the labour market suffers will not be a barrier to show and demonstrate the excellent academic background I have received since I was a child.

First of all, I am very grateful to Prof. Zorrilla, whose dedication and support to this project has enormously contributed to the correct performance in completing this bachelor thesis. I need to thank my parents, who have always provided me every means at their disposal to be a curious and responsible person. Special thanks goes to Eva, a fundamental pillar since the moment I had the opportunity to meet her, since without her support, it is certain that the completion of this period of my life would have been quite more difficult. I also wish to thank my Airbus colleagues, amongst them Nacho, Esther and Vanesa, their interest and support during the amazing year I have had the opportunity to be part of the A380 quality team.

Finally, as last but not at the least, I would like to express a special thank to one person I first met when I was only a child. During two different periods he gave me the opportunity to play football, my childhood passion, and to discover essential lessons that are crucial in life, as the importance of a job well done, the enormous potential and improvement capacity everyone has, or the importance of not to give up in difficult moments. Thank you Alfonso.

CHAPTER 2: ABSTRACT

Commercial aviation has become increasingly more accessible during last decades, due to a higher flight frequency, launch of new routes and affordable prices. Low cost airlines are playing an important role in this process, since these companies have achieved spectacular reduction in operational costs. In this context, users, companies and employees are conferring an increasing importance to certain terms, such as comfort, ergonomics or, in last term, work related musculoskeletal disorders (WRMSDs). These concepts are widely employed in the corporate sector, and most of companies incorporate occupational health and safety departments.

This project aims to import this methodology to commercial aviation, in order to define and assess a group of activities and seated positions commonly adopted by airplane passengers on their aircraft seats. The research employs direct methods of biomechanical analysis and specific software to evaluate whether biomechanical risk factors are present. Failure Modes and Effects Analysis (FMEA) will be employed as an auxiliary method to prioritize what postures require the implementation of modifications.

An important objective of this paper is to approximate and differentiate where is the limit between commodity and ergonomics, and in which cases a position ceases to be ergonomic, becoming uncomfortable.

Seated positions have been identified and grouped in five different categories: neutral postures, laptop/iPad postures, reading positions, sleeping postures and, finally, in order to group baby posture and eating posture there is a group under the denomination of other postures.

The research evidences different medium risk level postures that air passengers are exposed to develop, which are in the limit between commodity and ergonomics, as well as it is proceeded to detect factors and cabin layouts that directly affect in the flight ergonomics conditions.

CHAPTER 3: INTRODUCTION

3.1. Overview

The line of enquiry of this project aims to be defined and assigned from an ergonomic perspective. According to IEA (International Ergonomic Association), "ergonomics is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance" [4]. The relevance of ergonomic aspects –whose importance has experimented a growing weight, at the same time repetitive and longer tasks have achieved a capital function- is the design optimization. This optimization consist on the effects minimization of people limitations, and the strength complementation, and abilities of people with an ergonomic design, avoiding they were forced to adapt [5].

Nowadays, companies are aware of the relevance than certain terminology, such as commodity, usability, durability or security is conferred by their employees, their clients, and overall well-being of the system [6, 7]. As a consequence to those terms, companies invest great amounts of money, for instance, researching how to reduce absenteeism rates, especially in those positions that require a high repeatability rate or at workplace that requires to be in the same posture for long periods of time [8]. In this context, it has been decided to focus on an engineering and technological field, as design of transport systems.

Firstly, it would be important to distinguish between main transport systems can be found: if it is considered for this study inter-urban trips in a EU27 context, ground transport and air transport are the main forms of displacement European citizens chose [9].

Whether is made a preliminary study of transport by land, the majority of this kind of transportation is due to automotive sector. UNECE (United Nations Economic Commission for Europe) shows between years 2000 and 2008, Spain has increased total length of roads in 1.500 km, approximately. This figure includes a 3000 km reduction of State roads, Provincial roads and Local roads. Inversely, Motorways has enlarged their capacity in 4.500 km, what suppose a transformation in Spanish transport and logistic infrastructure. Despite this huge investment, passenger cars have diminished numerically from 1.467.160 in year 2000, to 1.188.485 in 2008 [10].

This reduction has occurred in full economic expansion, whilst Spanish population have tended to increase in that period. This passenger cars reduction, which could be explained attending to national issues, such high fuel prices, owing to the high energy dependence rate that Spain suffers, 76.4% in 2011, opposite to a EU27 energy rate of 53.8% [11].

Additionally, automotive industry has developed different models, which are in several cases an evolution from other existent car, and these new models have supposed a notorious improvement in terms of security, commodity and also from an ergonomic perspective [12, 13]. In terms of security, death of people involved in car accident is experimenting a constant and drastic reduction since year 2003 in Spain [14]. In order to find evidences about commodity and ergonomics improvements, both terms will be considered jointly, since lack of commodity derives necessarily in a lower level of ergonomics [15].

Ultimately, lack of comfort may suppose the apparition of different kinds of musculoskeletal disorders (MSDs in advance), which will frequently be mentioned along the project. Musculoskeletal disorders are defined as combination of minor physical disabilities. The term MSD is used for referring to any injury or damage which affect the joints in the back or upper/lower limbs, also including tissues which are located in these parts of the body [16].

According to CAA (Civil Aviation Authority), "air transport is the service that includes transporting passengers or freight, from a first place to a destination place, using commercial aircrafts, with the goal of making profitable this activity" [17]. Main characteristics of air transport, such as rapidity –aerial transport is the fastest way of transportation- or security - air transport is the way of displacement with the lowest rate of victims or injured passengers- have allowed this form of transport have grown exponentially during last recent decades [9]. In **Figure 1**, can be observed the air traffic routes between North America and Europe:

Figure 1. *Air Traffic routes between North America and Europe [18].*

According to IATA (International Air Transport Association), Total Passenger Market, which includes domestic and international users, reveals a spectacular increase in Revenue Passenger Kilometers (RPKs[1]). From year 2007 to half of year 2014, Total Passenger Market have passed from 3.62 bill to 5 bill RPKs, whether it is considered data seasonally adjusted. This information probes it is taking place a democratization over the air space [19].

[1] Revenue Passenger Kilometers (RPKs): This is the basic measure of airline passenger traffic. It reflects how many of an airline's available seats were actually sold. For example, if 200 passengers fly 500 kilometers on a flight, this generates 100,000 RPKs [20].

Below this words can be observed Total Passenger Market Evolution, in the period referred in last paragraph:

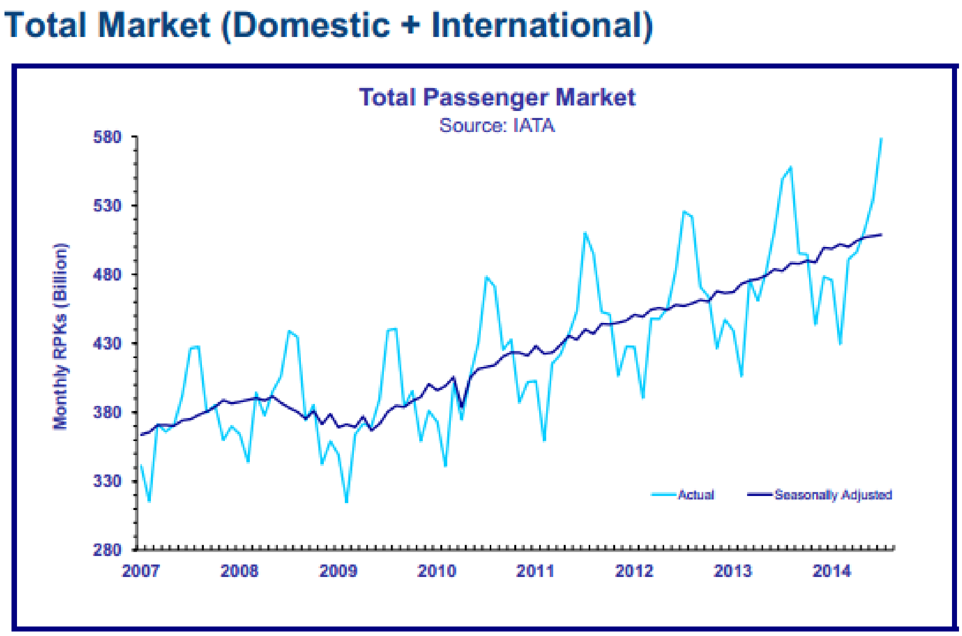

Figure 2. *Total Passenger Market. Period 2007 – June 2014 [19].*

As it was referred at the beginning of the project, the research line has been thought to be positioned in a situation in which ergonomics holds a primary relevance. Therefore, this project will be centered in the air transport of passengers, and how the aircraft interior comfort and design of different aircraft seat models affect on passenger ergonomics and what is the relevance of these designs for the apparition of diverse MSDs.

3.2. Precedents and problem identification

Nowadays, air travel is available and accessible practically for any citizen. Air transport have experimented a reduction of prices moderately during last decades, and citizens can now enjoy the advantages of relatively cheap flights. Air travel is also more accessible, due to the fact that airline operators can cater for all kind of individuals. Furthermore, airline operators decide the interior distribution lay out of the aircraft, so the airline, as a costumer, decide the comfort and spaciousness of the seating in their airplane. This fact has been possible especially with last generation of wide body aircrafts, which offer these airlines the possibility of choosing among a flexible package of seating options [21, 22].

Therefore, a primary element in an airline strategy should be to provide a superior comfort experience, whether the purpose of the operator is to increase the sales of tickets. But, in addition to this, there is an uncertain and unpredictable element which does not depend on the airline operators: the fact that only each passenger has the possibility to evaluate whether he or she is feeling comfortable. For this reason, passenger's own sense of comfort is one thing in which passengers have a higher level of knowledge and experience than flight attendants or airplane manufacturers. None of us can respond if a particular passenger feels comfortable or not while a flight is taking place, since that question can only be answered by each passenger who is experimenting that particular experience. Over this logical reasoning is one of the difficulties of designing for comfort, in the case of a company where comfort is essential to achieve success: the fact that each individual has his own subjective sense of comfort [23].

However, a complete study of 10.032 passengers reveals that it is possible to make passengers feel more comfortable during their air experience. To achieve an even higher level of comfort will be more difficult when this new higher comfort standard has started, but to get a higher comfort level since it was established initially it is still possible and it will increase the passenger experience, by making him or her feel more comfortable (Ibídem).

Opportunities to Influence Comfort	
Comfort Process Phase	**Opportunities**
Expectations	Optimize brochures, web sites, check-in system, site choice
First sight	Nice entry, good locking interior, spacious sitting place
Short-term comfort	Positive attention of crew, a personal gift
Short-term discomfort	Seat feels good, no obstacles, no pressure, no stress on the body
Long-term comfort	Unexpected positive attention, popular movies, good view, opportunities for the passengers to do their activities
Long-term discomfort	Variation in posture possible, good form, and cushioning of the seat
Restore or affirm	Tell that the bad experience was an anomaly, offer a possibility to complain, or affirm the good experience

Table 1. *Opportunities to Influence comfort [23].*

Apart from experiencing different levels of comfort, the passenger is also subject to experiment a certain level of discomfort in the aircraft, as well as the possibility of suffering from psychological stress previously or during the air travel. People can also experience other situation related to the air travel process, as a feel of unfamiliarity with the food which is served in the airplane, a wide variety of seat designs, the seat positions and its configuration in the aircraft interior, or different environmental conditions in the aircraft cabin that the passenger may experience. Furthermore, the flight duration combined with the changes of time zone are a capital factor to take into account, since it may cause jet lag, an imbalance that affects the passenger's health in a significant way [21, 22].

Whether the passenger has a preventive behavior, which only consist on taking into consideration some simple considerations of health risk associated with air travel, these risks can be easily minimized. To prevent and minimize these specific risks successfully, it will be necessary to pay attention to these precautions before, during and after the air travel. Next paragraphs contain a detailed explanation of different factors that may affect the health, comfortability and well-being of air passengers [24].

Cabin Air Pressure

Despite the fact that airplane cabins are pressurized, the pressure a cabin experiments at cruising altitude is lower than the air pressure at sea level. In the range of 11.000-12.200 metres, which is a normal cruising altitude for a commercial aircraft, the air pressure which is experimented in the interior of the airplane is similar to the outside air pressure at 2.000-2.400 metres over the sea level. This means that the blood contains a lower level of oxygen. This condition, which takes place in the body or in a region of it is known as hypoxia and, as we have explained previously, is basically an inadequate supply of oxygen to the body. This effect consist on a reduced cabin air pressure, is regularly well tolerated by healthy passengers (Ibídem).

Cabin humidity and dehydration

Other atmospheric factor that differs from our daily life during an air travel is the humidity. At home, humidity is generally over 30%, but this percentage goes down to 20%, whether we consider humidity in aircraft cabin, when an air travel at cruising altitude takes place. Although this fact does not cause dehydration -so it is not necessary to be hydrated in excess before travelling by air- low humidity can result in skin dryness and discomfort of the mouth, nasal region and eyes. These discomfort can be minimized employing moisturizing lotions or sprays in the part of the body in which it is required (Ibídem).

Ozone

Ozone is a molecule which is composed of three atoms of oxygen. The origin of ozone is in the upper part of the atmosphere, so physically the natural location of ozone coincides with the cruising altitude of an airplane. This suppose that ozone may enter the aircraft cabin through the ventilation system together with the fresh air, in small quantities. In older airplanes, airline operators have found these low levels of ozone can result in the irritation of the nasal cavity, the lunges or the eyes. The particle of ozone is decomposed by heat and this reaction occurs in the compressors of the aircraft, which are located in the airplane engines. The mission of the compressors is to provide pressurized air for the aircraft cabin. Apart from the compressors, last generation of long-range wide-body aircrafts are equipped with catalytic converters which breaks down any rest of ozone (Ibídem).

Motion sickness

Despite what it may seem, air passengers do not normally suffer from motion sickness, excepting the case that the aircraft is going through a patch of severe turbulences, such as a lighting storm. If this was the situation, what the travellers who are sensible to suffer from motion sickness with certain facility should do is to be sat in the mid-section of the airplane, since this area of the cabin experiments the less pronounced movements of the plane. In addition to this, it would be convenient to have accessible the motion sickness bag that is provided for each passenger at the seat (Ibídem).

Jet lag

Jet lag is an imbalance that consists on the disruption of the body's internal clock. This disruption takes place when a passenger is constantly travelling and crossing multiples time zones. Jet lag may produce, in frequent travellers, several anomalies and discomfort, such as sleepiness during the day and difficulties for sleeping during the night, general tiredness that may affect our physical and mental performance, as well as indigestion or emotional unease. These symptoms gradually diminish, at the same time that the body get used to the new time zone (Ibídem).

As a curiosity, the only situation that will cause an air passenger jet lag is flying due east or west, since if we travel between two destinations with no time difference, for instance, from Rio de Janeiro to Greenland, we will not experiment jet lag symptoms, but only the normal fatigue of being travelled during the hours that correspond to this flight [25].

The way that jet lag has to be treated, in order to reduce its effects, is to have a good knowledge of your body and your specific situation, as if you take medication regularly, following strict timetables. In this case, what we should do is to seek for medical advice before the journey [24].

As an indicator of the importance jet lag is being conferred, different airline operators, such as British Airways, has included on their website an application called Jet lag advisor, which consist on advising you on the best things to do to minimize your jet lag, by answering a few simple questions regarding your recent or planned flights [26].

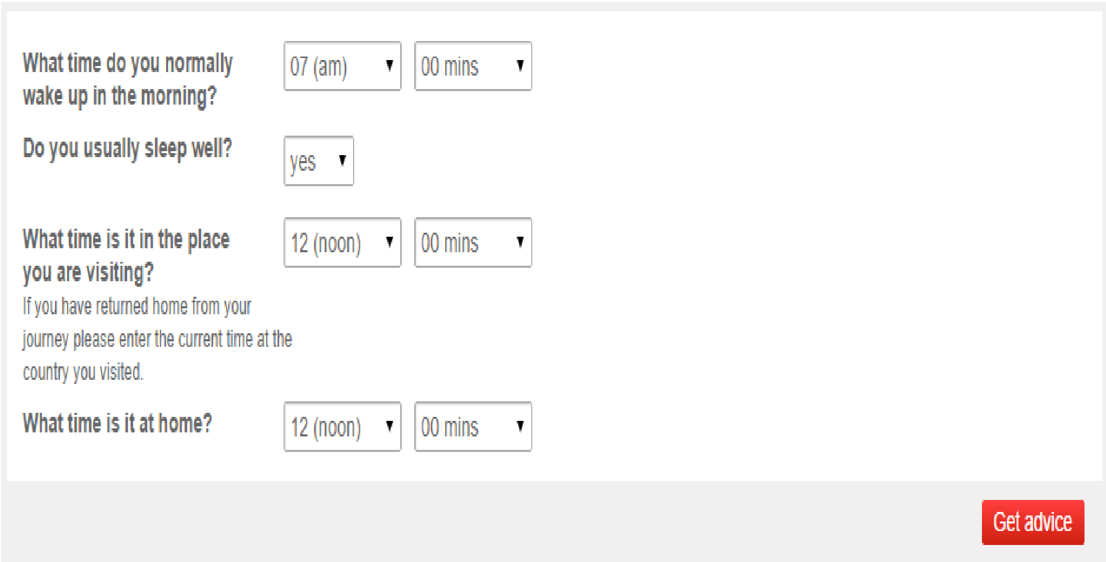

Figure 3. *Jet lag advisor [26].*

Pressure and touch

There are different studies in which can be appreciated the relationship and the connection that exist between two concepts: pressure and discomfort [27, 28]. People feel pressure through different sensors we incorporate in our skin. Only reducing the pressure we exert between the human body and the seat or the handle, we get a better distribution of pressures during an air travel which, in last term, allow us to reduce our perception of discomfort. Body pressure is an important factor to be taken into consideration, since according to an exhaustive literature survey [29], pressure is the factor which has a stronger direct relationship with discomfort [23].

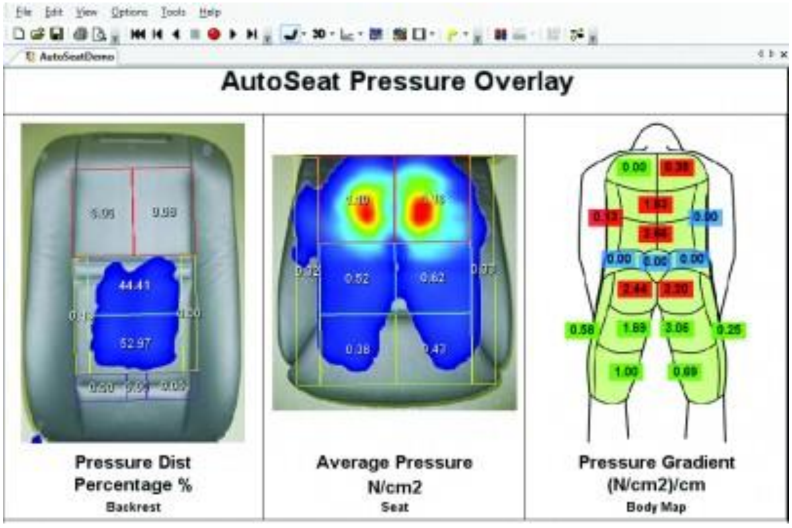

Figure 4. *Comfort analysis test [30].*

Immobility, circulatory problems and Deep Vein Thrombosis (DVT)

Contraction of muscles is an important factor that improves the blood flowing through the veins, what occurs always it is adopted a motion in a part of the body. Contraction of muscles is an important factor for the thesis case of study, particularly in legs, because when a passenger is seated during an air travel, legs are the part of the body that experiment in a higher level prolonged immobility. This fact can lead to pooling of blood in the legs and this may conduct the passenger to suffer from discomfort, rigidity and inflammation [24].

But the main risk of suffering from immobility is not to feel discomfort or swelling, since immobility is one of the factors that can cause a DVT, which means “deep vein thrombosis”. DVT occurs when somebody experience the development of a blood clot in a deep vein. Whether an air passenger sits for long periods of time, he or she increases the risk of suffering from DVT, especially in the veins of your legs. Researchers has proved this statement, since during a long distance travel, our body in general experiment a prolonged immobility, but our legs in particular are the region of the body which have a greater risk of experimenting deep vein thrombosis (Ibídem).

Despite DVT is a risk to take into consideration in periods of prolonged immobility, clots are normally small, and so the passenger does not normally suffer from any symptoms. This happens because the body is able to break down these small clots, so that the passenger will not suffer from any secondary effect. It might happen, however, that larger clots would not totally break down. If that were the case, the traveller could experience some typical symptoms, such as a slight inflammation in legs, pain and tenderness. It could also occur that a part of the clot travelled with the bloodstream, becoming stuck in the lungs. In this case, the clot would derivate in a pulmonary embolism and the symptoms in this case are chest pain and shortness of breath, mainly. In severe cases, pulmonary embolism could derive in sudden death. The period of time in which pulmonary embolism can be developed goes from a few hours to days, since the formation of the initial blood clot (Ibídem).

As the WHO (World Health Organization) says, “the risk of a passenger who does not have any of the risk factors above developing DVT as a consequence of flying is small and the benefits of most precautionary measures in such passengers are unproven and some might even result in harm”. For these cases, airline operators are developing quick user-friendly guides in order to advice the passenger for reducing immobility during an air flight (Ibídem).

Some simple in flight exercises are given below, with the aim of preventing DVT in passengers who frequently travel by air.

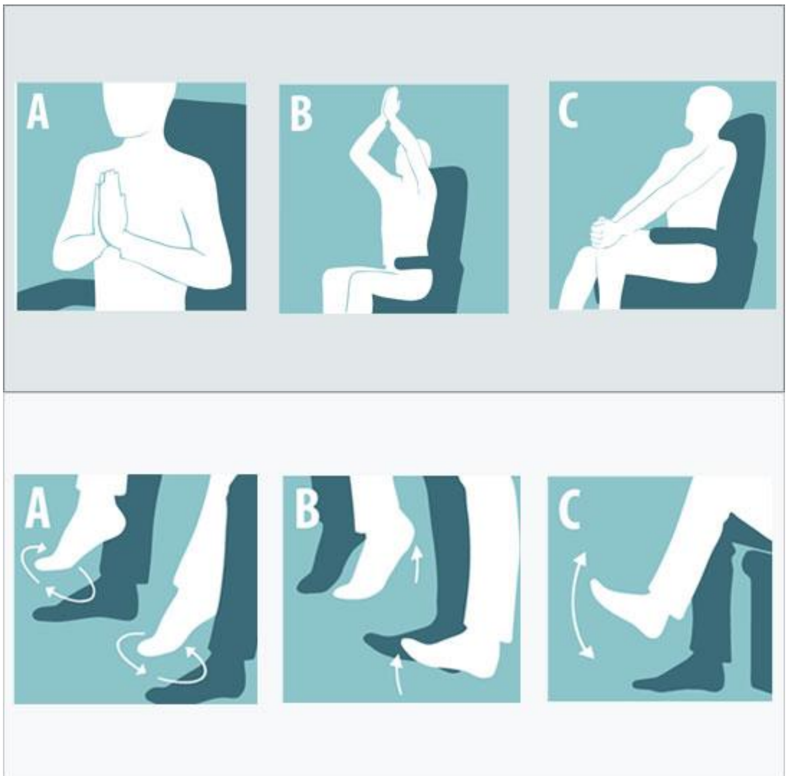

Figure 5. *In flight exercises to prevent DVT [31].*

Apart from these exercises, other kind of movements can be done in order to prevent and reduce any period of time with a low level of mobility. One example consists on moving around the aircraft cabin during the air flight. However, the realization of this prevention activity may not always be possible, since if the airplane can be flying thought a turbulence area, or encounters with it suddenly and the passenger could suffer an injury, an unnecessary risk that the airline operators should avoid. Other possible solution for minimizing immobility in flight consist on establishing a regular period for going to the bathroom once each 2-3 hours, what also allows the passenger walking around the cabin. But there are some muscles that airline operators remark on their advices to reduce immobility: calf muscles. Calf muscles are specially recommended to be stimulated, since studies prove that the stimulation of this region of the body improve the circulation and reduce general discomfort, apart from diminishing fatigue and stress (Ibídem).

Other steps that can help to reduce the risk of suffering from circulatory problems are, among others, to wear loose and comfortable clothing, and keep your hand luggage in the luggage compartment that airplanes incorporate on the upper area of the seats, along the aircraft cabin (Ibídem).

Posture and movements

Each product, included aircraft seats, determines different movements and postures that the user –in this case the user will be a passenger- adopts when using the product. If this postures and movements result in discomfort, and this situation is maintained during a certain period of time, discomfort could result in MSDs [23, 32].

In the fourth European working conditions survey, which took place in year 2007, European citizens were requested about the most common health problems, whose cause is attributable to their work place. The majority of the answers reflected that most often health problems are related to backache and muscular pains, both are types of MSDs. Furthermore, the survey revealed that one-third of European workers suffer from back pain, and one-quarter of the people who were surveyed suffer from neck or shoulder pain [23, 33].

Figure 6. *The new seats are slimmer so they are being fitted closer together [34].*

3.3. Definition of pain and introduction of work-related MSDs

Nowadays in this society, pain has become a benchmark as a concept, especially for the field of health sciences. IASP (International Association for the Study of Pain) defines pain as "an unpleasant sensory and emotional experience associated with actual or potential tissue damage, or described in terms of such damage". Pain is a mechanism of protection which is perceived when a person has suffered a psychical damage. In clinical terms, pain is an unpleasant sensation which is experimented after having suffered a tissue or nervous injury. Therefore, pain is an indicator for the assessment of body damage [35, 36].

Pain is classified by researchers in two general types, which are based on its time course [37]:

- Acute pain, which is conceived as a response due to tissue damage. Acute pain's duration might be for a short period of time, or it might last for weeks or even months, in severe cases. In case a person experiments acute pain, the intensity is usually mild, and it disappears when the origin of pain has been treated. However, whether acute pain persists steadily, this type of pain might lead to chronic pain [38].

- Chronic pain is characterized by the pain signals remain active in the nervous system for weeks, months or years, despite the fact that the injury has healed. Physical effects a person experiments while he or she suffers a chronic pain include a lack of energy, limited mobility and tense muscles. The most frequent complaints that people who suffer from a chronic pain include (Ibídem):

- Headache
- Low back pain
- Cancer pain
- Arthritis pain
- Neurogenic pain
- Psychogenic pain

Chronic pain is normally caused by an initial injury or trauma. However, in some cases people suffer chronic pain without having suffered any past evidence of body damage of injury (Ibídem).

The concept of pain contains two different aspects: sensory and emotional. The sensory aspect makes allusion to the sensations whose origin is in the stimulation of the pain receptors. The emotional aspect makes reference to the level of pleasantness of the pain [37].

Pain perception involves different areas of the cortex, and the role of each of these areas requires to be worked out to the fullest. Main areas in which the sensory aspects of pain are associated are the somatosensory area 1 (SS1) and the somatosensory area 2 (SS2), as can be observed in the image below. Emotional aspect of pain is associated with an area in the frontal lobes, which is known as the anterior cingulate gyrus (ACG) (Ibídem).

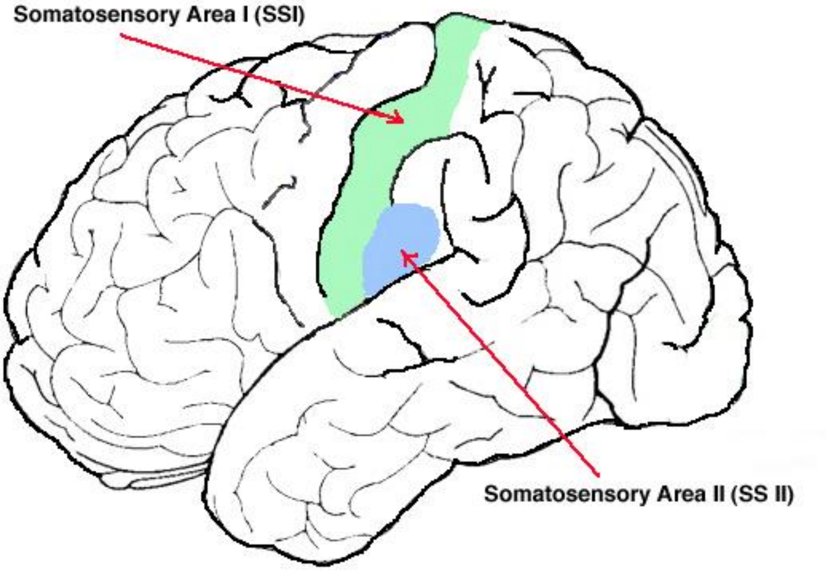

Figure 7. *Areas of cortex involved in pain perception [37].*

Throughout the project are treated different issues and connections among them, such as ergonomics, air transport, commodity or discomfort and pain. The mixture of all this elements give rise to another concept has been treated previously: **WORK-RELATED MUSCULOSKELETAL DISORDERS** (**WMSDs**).

During the performance of different activities, such as walking, running, dancing or travelling, the musculoskeletal system is under a usage period. The musculoskeletal system has a high degree of complexity, since it is composed of a wide variety of tissues. Musculoskeletal system is essential for the correct maintenance of an appropriate posture. Repetitive work or holding heavy materials may damage the system and, therefore, the performance of these activities might lead to musculoskeletal fatigue or pain [39].

The cause of MSDs is an inappropriate balance in physical capacity of muscles, joints or ligaments, among others, with external loads that act on the human body. Despite the fact of external loads may give result to acute trauma, leading to fractures or contusions, MSDs are mainly cumulative disorders. The origin of these cumulative disorders is due to the repeated exposure to a combination of load during a long period of time (Ibídem).

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MSDs are developed when the musculoskeletal system is affected, as a result of a repetitive exposure to external forces. Main parts of the body which are particularly vulnerable to MSDs are the upper limbs, the neck and the lower back (Ibídem).

Main types of injuries can be categorized under the field of work-related MSDs are [40]:

- Muscle injury.
- Tendon injury.
- Nerve injury.

Muscle Injury

Muscle contraction means the consumption of chemical energy. When the contraction last a long time, the substances that are produced by the muscular activity, such as lactic acid, are not removed by the blood correctly, which finally results in a blood flow reduction. If this sequence is maintained during a prolonged period, the lactic acid is accumulated in the muscles, what irritate the muscles and cause pain. Depending of the duration of the contraction and the period of time available to remove these irritating substances, the intensity of the pain is variable (Ibídem).

Tendon Injury

Tendons are a group of fibres which are bundled up, in order to keep muscles affixed to bones. Repetitive or frequent activities may cause tendon disorders, which can be grouped in two major categories: As can be observed in Figure 7, the first category includes tendons with sheaths, which are mainly found in the hand and wrist. Figure 8 represents the group of tendons without sheaths, which are generally located around the shoulder and the elbow (Ibídem).

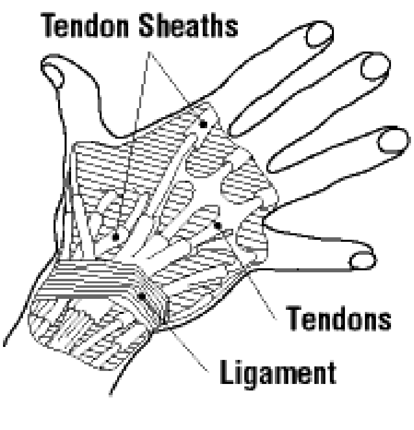

Figure 8. *Finger tendons and their sheaths [40].*

Repetitive or excessive movement of the hand increase exponentially possibilities of collapsing the lubrication system. This system consists in a group of cells in the inner walls, which produce a fluid whose mission is to provide lubrication to the tendon appropriately. Whether this protection system for the tendons fails, friction between the tendon and its sheath entails inflammation around this area. When the intensity in the movement persists, the repetition of this episodes of inflammation lead fibrous tissue to thicken the tendon sheath, and complicates tendon movement (Ibídem).

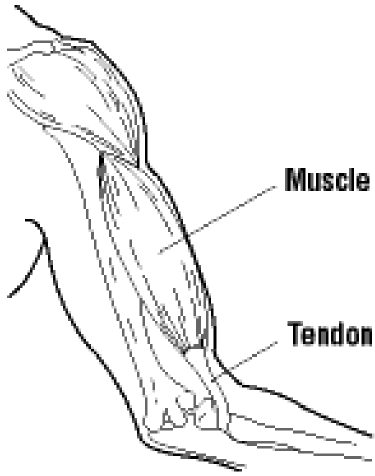

Figure 9. *Tendon, muscle, bone unit [40].*

Tendons without sheaths are exposed to a higher risk of being damaged, when repetitive movements or uncomfortable postures are adopted. In these cases, some of the tendon fibres can tear apart, whether the muscle tissue is repeatedly tensed. This cause the tendon inflammation, due to the increase of thickening. Tendonitis is the medical term which indicates the inflammation of the tendon (Ibídem).

Nerve Injury

Nerves are those element whose function is to transmit the signals that are originated in the brain, and whose finality is to guide the muscle activity. Apart from this, nerves are also responsible of carrying information about other variables from the body to the brain, such as the temperature or the pain. Nerves are located together with muscles, tendons and ligaments. Uncomfortable postures and repetitive movements cause the compression of nerves, since the tissues that surrounds the nerves become swollen, as can be observed in Figures 9 and Figure 10 (Ibídem).

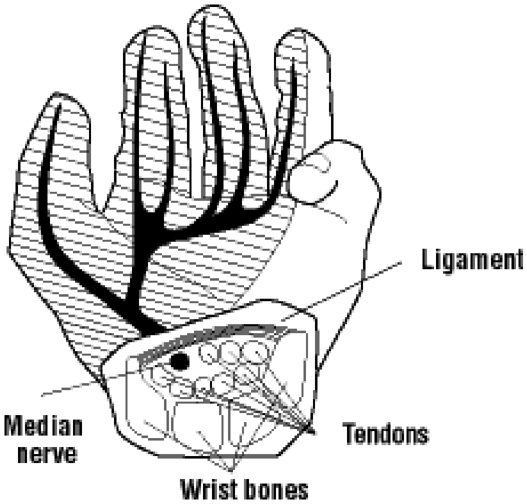

Figure 10. *Wrist in natural condition [40].*

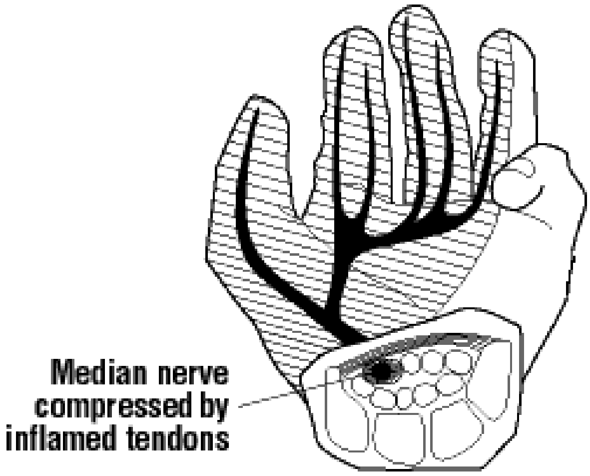

Figure 11. *Wrist showing symptoms of Carpal Tunnel Syndrome [40].*

3.4. Objectives and hypothesis

Presently, it has been introduced current situation in commercial aviation, as well as it has been identified main considerations of health risk associated with air travel ergonomic that airplane passengers are exposed to suffer. The next points contain objectives required to conduct this project:

- The first objective makes reference to the necessity of establishing a methodology that enables a correct analysis and assessment of different postures any air passenger may adopt while he or she is sat on a plane seat. The pretension of this analysis is to approximate and differentiate where is the limit between commodity and ergonomics, and in which cases a position ceases to be ergonomic, becoming uncomfortable. Discomfort may also become in a potential risk to develop a MSD.

- The second objective is the establishment and identification of working postures and common seated positions that airplane passengers commonly adopt. The aim of this identification is to promote airlines and manufacturers consider a group of reference postures that are acceptable in terms of ergonomics, while cabin layout or aircraft seats are being designed.

- Third purpose is the development of a biomechanical ergonomic study with the minimum possible cost and supported by computer tools, what minimize interferences with the air passengers. To achieve this goal, it will be a priority software applications incorporate a free trial period, to reduce the cost of the project.

- Finally, airplane passengers, as the rest of people, may be ranked in percentiles, according to anthropometric data, which includes the height and the weight by sex. This project will consider, inasmuch as selected ergonomic applications allow for it, different anthropometric groups while aircraft seating postures are being assessed. This pretension is due to the fact aircraft seats dimensions are thought for a common pattern, but air passengers do not correspond in many cases with that pattern, so it would seem obvious that the results obtained after the ergonomic assessment will not be exactly the same.

This study also takes into account certain working hypotheses, which are outlined below:

- Static analysis implies loads are gradually applied, till the full magnitude is achieved. At that time, loads will remain constant and do not vary over time. This research is conducted under static conditions for airplane passengers.

- Certain postures airplane passengers adopt when they are seated on their aircraft seats may give rise to an increase in passenger’s level of discomfort. Discomfort will be significant when ergonomic risk assessments detect a position is at the limit of what is permitted, in terms of ergonomically acceptable/non acceptable.

CHAPTER 4: METHODOLOGY FOR ERGONOMIC ANALYSIS

4.1. The sitting position

The sitting position is the posture the body adopts when a person is sat on a seat, including aircraft seating. In order to reduce MSDs during air flight, we are going to give some pieces of advice, which firstly will enable any air passenger to know different reference postures can be adopted to provide the body a neutral positioning [41].

In case of those air passengers who take a plane with a high frequency of time, next considerations will ostensible be useful, in order to maintain neutral body postures and reducing the development of musculoskeletal disorders (MSDs) (Ibídem):

- Hands, wrists and forearms are straight and in-line, trying to be maintained parallel to the floor.
- Head is level and balanced, being generally positioned in-line with the torso.
- Shoulders are relaxed and balanced with the torso.
- Elbows form an angle between 90º and 120 º, staying close to the body.
- Feet are supported by the floor so that they experiment a full contact with the floor, whenever possible.
- Back is fully supported, which will be achieved by trying the highest level of contact with the chair's support surface.

The definition of a good posture, attending to biomechanical principles, is directly related to a symmetrical alignment of body segments, besides the balance of the skeleton. According to Engström, in those cases in which the body is in accordance with mechanical rules and, therefore, the body experiments a higher level of comfort and balance, the subject who is sat tends to be more erect [42, 43].

Following this general considerations, the main reference postures that are supposed to provide neutral positioning to the body are [41]:

- Upright sitting posture.
- Declined sitting posture.
- Reclined sitting posture.

Upright sitting posture

Traditionally, one of the most frequent postures people adopt when we are sat, and which is the pattern in human furniture designs and a reference for development of most of our daily activities, which require to adopt a sat position is the upright sitting posture. In this posture, the user's torso and neck form an imaginary vertical line, hips and knees are flexed, adopting a 90º angle, thighs are approximately in horizontal position and the lower legs are vertical [44].

Consequently, upright sitting posture may be seen as a reference in the ergonomic field, whether we specially pay attention to anatomical aspects, the aim of this posture is to provide the user a high level of orthopedic symmetry between both sides of the body [42, 45]. This symmetry is achieved by a neutral pelvis collocation, which enables avoidance of rotation, obliquity and posterior pelvic tilt [45]. The adoption of this posture will help the user to achieve, in last term, one of the main goals of seating, as to promote relaxation and comfort is [43, 46].

Figure 12. *Upright sitting posture is based on the 90-90-90 flexion at the knees, hips and ankles position [47].*

Despite the fact that upright sitting posture is a recommended posture to adopt for users who pretend to be sat, this position is suggested as a complicated posture for being maintained during a long period of time [48]. This situation lead the human body to adopt other compensatory postures, which may suppose long term discomfort and further deterioration if, in our particular case, aircraft seating solutions are not enough robust. The appropriate solution may require a balance between the consecution of a symmetrical posture and an appropriate functionality and equipment of seating solutions [43].

Declined sitting posture

In this posture, the user’s upper legs are inclined in comparison with upright sitting posture, in which thighs were in horizontal position. This cause the buttocks are higher than the knees, as well as the angle formed by the thigh and the torso exceed 90 degrees. Torso and legs position is vertical, although the torso may be slightly stretch out [49].

Figure 13. *An air passenger who adopts a declined sitting posture, according to previous description [50].*

Reclined sitting posture

The last posture we have included among main reference postures for maintaining body neutral positioning during an air travel is reclined sitting posture. When the user adopts this sitting posture, the torso and neck of the passenger are straight and reclined, forming an angle of 105-120 degrees from the upper legs [41, 49].

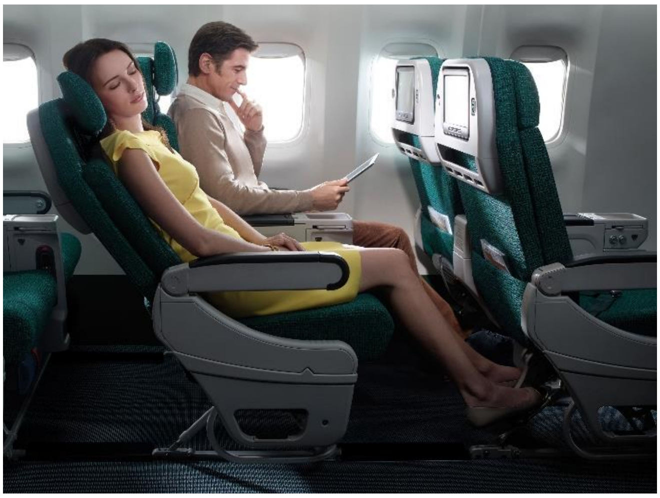

Figure 14. *A passenger reclines their aircraft seat, adopting a reclined sitting posture [51].*

Apart from this three reference postures, passengers may also experience during their flight a wide range of auxiliary positions. This group of postures, in addition to upright, reclined and declined sitting posture, represent a realistic guide for the analysis process this project incorporates. Some of the auxiliary positions any air passenger may adopt during an air travel are:

Laptop / ipad posture

Laptops do not fulfill basic ergonomic requirements, so using a laptop during an air travel suppose the adoption of a poor head/neck posture and a poor hand/wrist posture. Some key indications, in order to optimize comfort while using the laptop are [52]:

- The user must position the laptop on a surface which is in front of him or her. With this action, the user achieve to see the screen while minimizing to bend the neck.
- Pay attention to the angle between the forearms and the upper arms, and verify the elbow angle is close to 90º, since the keyboard height should allow the user to maintain that position.
- Intensive keying tasks should be done, as much as possible, adopting an upright posture. For other non-intensive tasks, the user should adopt, if possible, a slightly reclined posture.

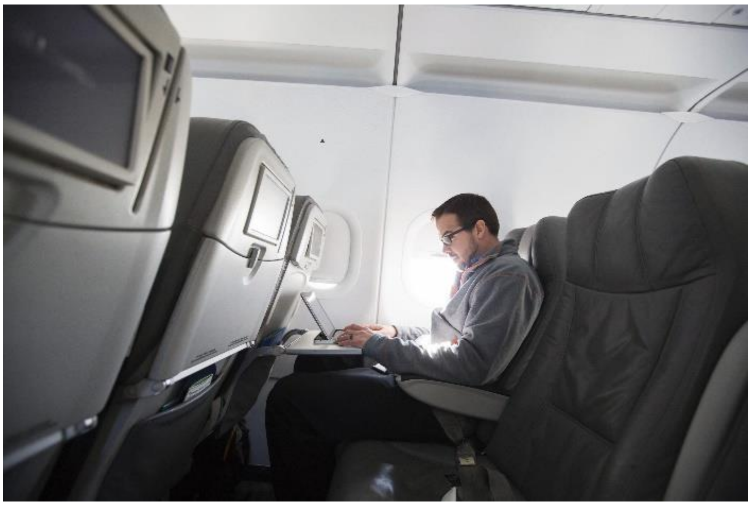

Figure 15. *An air passenger working with his laptop [53].*

Additionally, as an aircraft is one of the most challenging environments to navigate, and also incorporates remarkable peculiarities for computing, some considerations are given in order to optimize this activity (Ibídem):

- The user should try to reserve a bulkhead sitting or exit row for his or her trip. The exit row provides a wider space seat to seat, what permits to position the user arms more comfortably while working. Bulkhead seat benefits are the passenger does not suffer front reclined seat.
- In case the passenger decides to recline his or her seat fully, whether viewing angles and postures should be adopted cannot be adopted due to ergonomic aspects, it may be better not to use the laptop.

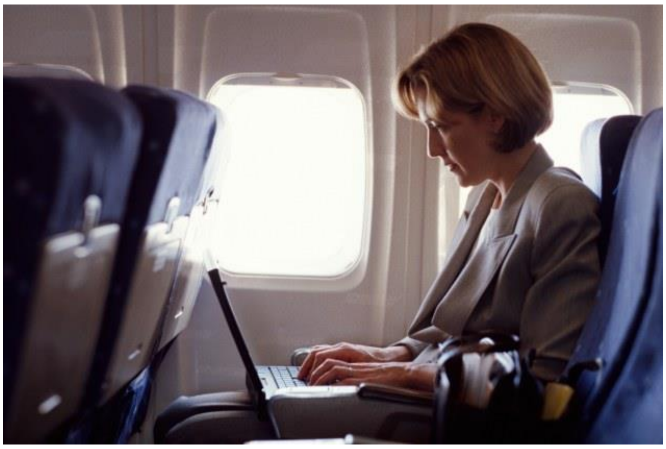

Figure 16. *A passenger seated with the laptop leant on her legs [54].*

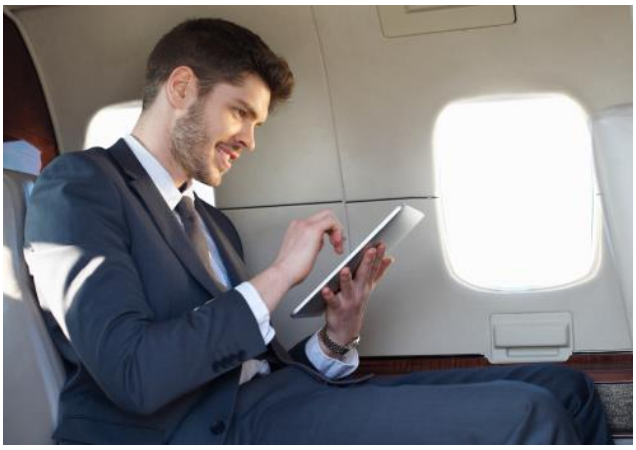

Figure 17. *An air passenger holds his iPad with the left hand [55].*

Reading position

The action of reading a document, either a book or a newspaper during an air flight, represents a postural challenge. A common posture consist on holding the book on the passenger's lap, which give rise to the passengers tend to adopt a rounded and slumped posture [56].

In case the passenger hold the book in front of himself, by flexing the arm at the shoulder joint, the subject will be exposed to a higher level of fatigue. This is caused due to the fact of the deltoid must isometrically contract, when the passenger adopts this position (Ibídem).

Figure 18. *Reading posture with flexed arms at the shoulder joint [57].*

An alternative reading posture consist on supporting the arm whose function is to hold the book. The optimum way to achieve this is to place the arm that holds the book on the forearm opposite side (Ibídem).

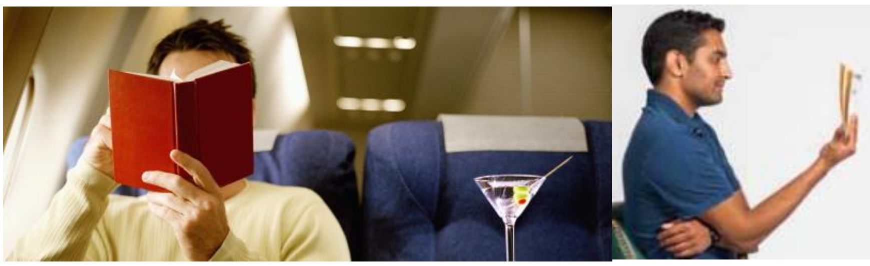

Figure 19. *An alternative reading posture, supporting the arm that holds the book [58].*

Sleeping posture

During an air flight, especially on long haul travels, passengers tend to sleep during the air travel. This is caused by the high period of time passengers are sat in their aircraft seat, what reduce level of comfort [3].

Passengers may adopt a wide variety of sleeping positions, which have perfectly been identified and grouped in four general sitting postures. This classification also considers a pillow as an auxiliary element to increment the passenger's neck support (Ibídem):

1. Neutral position.

2. Slid down on seat in neutral position:

• With pillow.

• Without pillow.

3. Head in tilted position (left and right):

• With pillow (between shoulder and head).

• Without pillow.

• Supported with hand (between shoulder and head).

4. Torso sitting position:

• With pillow (head in diagonal with backrest).

• Without pillow (head in diagonal with backrest).

• Head resting on head rest (head perpendicular with backrest).

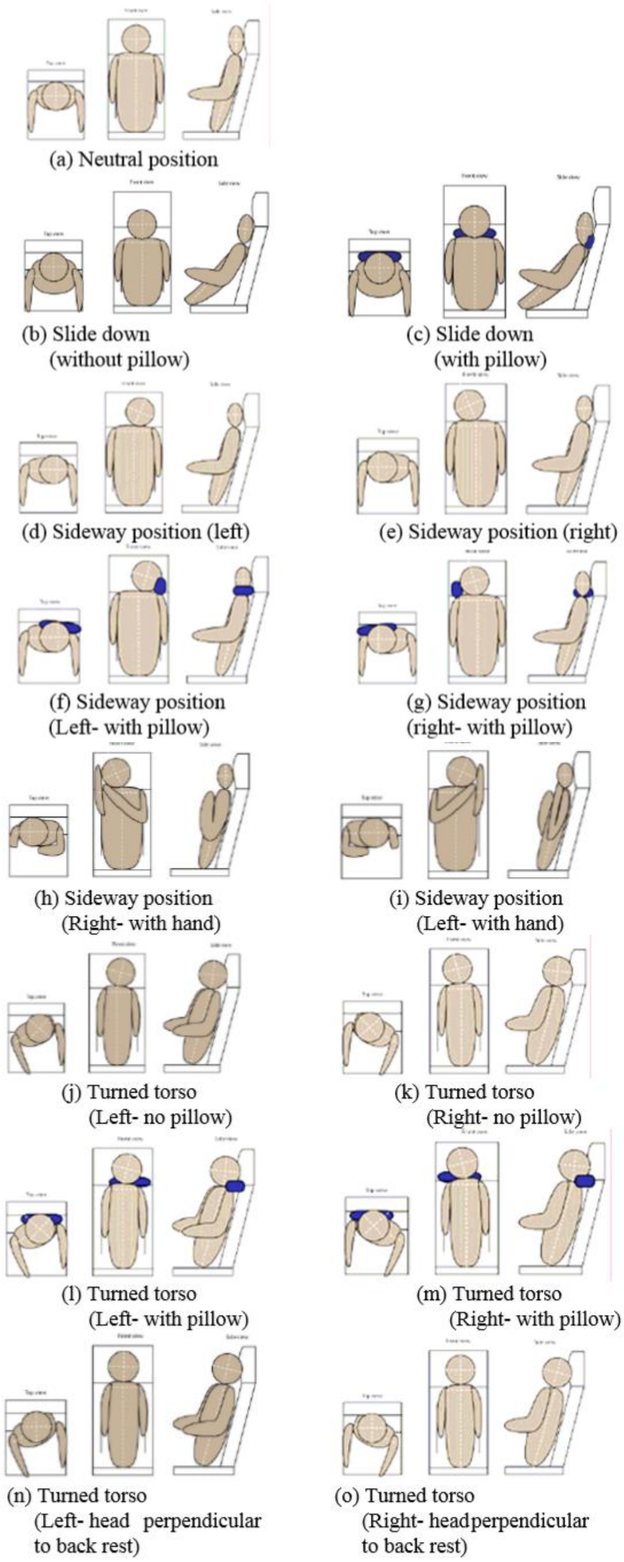

Figure 20. *The sitting position while sleeping [3].*

In addition to traditional seat concepts, Air New Zealand introduced in year 2010 a new way of travelling with the Skycouch. This revolutionary lie-flat seat is composed of a row of three Economy seats, which enable the creation of a flexible space, in which passengers can relax and sleep on a flat surface on long-haul flights [59].

Figure 21. *The Skycouch [60].*

Lastly, two additional positions that are common to be found during an air flight are given below:

Baby posture

Figure 22. *A passenger with a baby leant on her legs [1].*

Eating posture

Figure 23. *A passenger enjoys her in-flight meal [2].*

4.2. Methods for ergonomic analysis

This section will describe main methods for ergonomic analysis theories which are trends in implementing and developing methods of workplace analysis. Specifically, have been selected those from a wide variety of ergonomic analysis methods that can be applied to our case study in particular: a passenger sat in a plane seat during a plane trip.

In our case in particular, will be mainly applied methods of direct observation, in order to develop diverse strategies for evaluating ergonomic risks in our study case, the passenger who will experiment a plane trip.

One of the greatest strengths that direct observation confers to the observed is not to interfere between the user and his or her normal interaction with the product. However, direct observation also has disadvantages, as the observer has to interpret the interaction user-product without any active clarification of the user, so cannot be controlled different experiences the user faces and direct observation does not allow to interpret by itself. In order to make possible this experiences may be seen and interpreted, direct observation needs to be complemented and supported by other techniques [61].

Therefore, after direct observation techniques have been applied, the case study will be complemented by auxiliary methods of biomechanical analysis, whose aim is to reinforce primary results will be obtained from methods of leading to any different conclusions, if this is the case.

Biomechanical analysis is a type of study that defines and reflects how one moves. The importance of this technique of study lies in the fact that, whether by biomechanical analysis we can obtain a deep knowledge of how an injured person is moving, the quick implementation of a treatment will be much more accessible, besides the prevention of a potential injury [62]. Because of this, we will apply both methods, in order to arrive at useful and robust conclusions.

4.2.2. Methods of direct observation

In this section are outlined different strategies, with the aim of developing a successful method for evaluating ergonomic risks.

For our case study in particular, the passenger who is sat in a plane seat during a plane trip, we will focus on methods for detailed analysis. Methods for detailed analysis are those that follow the principle of relation between the method and biomechanical risk factors [36]. Specifically, we will carefully pay attention on forced and static postures [36, 63], which are fully experimented by our air passenger:

Forced and static postures

Static postures are those that consist on holding the same posture or position during a prolonged period of time, and suppose for the person to make a physical exertion. Static postures contribute to fatigue, since types of physical exertion included among those postures imply a high grade of loads and forces on the muscles and tendons. This contribute to fatigue because immobility of a part of the body impedes the correct circulation of the flow of blood, which does not allow nutrients are brought to the muscles correctly and collect the waste products that muscle metabolism produce [64].

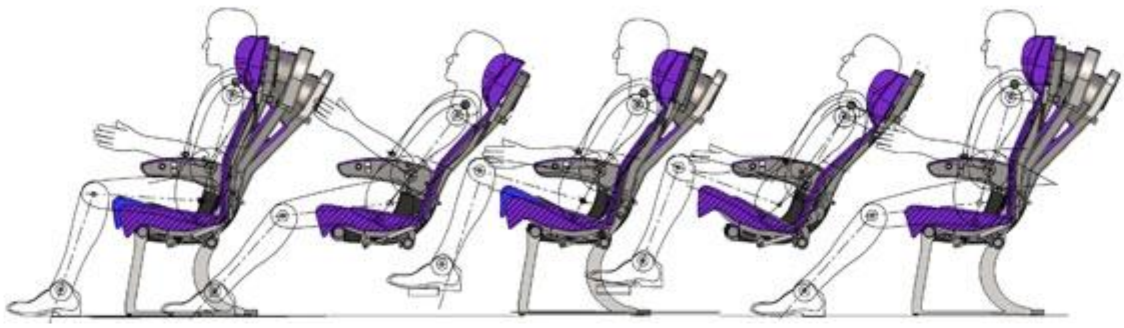

Figure 24. *A passenger regulates his plane seat [65].*

When the position must be maintained during a prolonged number of seconds and time is gradually raised, the effects on the body from doing these tasks are intensified. In case the passenger adopt extreme postures, what suppose the apparition of very high static loads on the body, the traveller will experiment a rapid fatigue, but not only due to the additional muscular effort that implies being on an static posture, but the lack of motion, as we argued in the preceding paragraph, complicates the correct functioning of the circulatory system, which is necessary for tissue recovering (Ibídem).

Identification criteria for forced and static postures occur if, during the period of action, take place any of this postures [36, 63]:

- Any static work posture (hold during a period of more than 4 consecutive seconds) of the trunk, upper limbs, lower limbs, the neck or other body parts.
- Any dynamic work posture (movements) of the trunk, the arms, the head, the neck or other body parts.

Characteristics associated to forced and static postures are the frequency of the movements, the duration of the posture, trunk postures, neck postures, the upper limbs postures and the lower limbs postures (Ibídem):

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Frequency of the movements:

The continuous fulfillment of movements from any body part until arriving at a forced posture increase the level of risk exposure. Therefore, whether the frequency of movements is higher, the risk will increase due to the physical demand which requires a higher velocity for the movement. If a greater range of motion takes places in time, it will suppose a higher level of risk exposure.

Duration of the posture:

Maintaining the same posture for a long period of time also suppose a factor which increase possibilities of developing WMSDs. This will increase the greater the time this posture has been maintained.

Trunk postures:

Trunk flexion, axial rotation and lateral bending are positions that must be identified jointly with the inclination angle. Adopting these positions above the acceptable limits of articulation, there may be a significant level of risk.

Neck postures:

Forced head and neck postures are linked to the observation of the elements that are outside the field of view angle, and these are: neck flexion (forward), neck extension, lateral bending and axial rotation.

Upper limbs postures:

These movements or postures are adopted mainly to interact with objects at a level above the shoulder.

Lower limbs postures:

The lower extremities, including the hip and legs, have a variety of joint movements among which may be mentioned: knee flexion, ankle flexion and ankle dorsiflexion, among others.

Pure static postures

In our study case, the passenger is only subjected to pure static postures without body motions, since we consider the subject of study is sat in their plane seat in every moment, without experimenting any relevant displacement that affects to his body. Static postures cause certain isometric muscle contractions (Ibídem).

Therefore, its characteristics will be coincident with those of the static postures: trunk postures, neck, upper and lower extremities which are developed and the duration of the posture. However, the frequency will not be similar, since for the simple fact it is an isometric movement shall not be undertaken other activities (Ibídem).

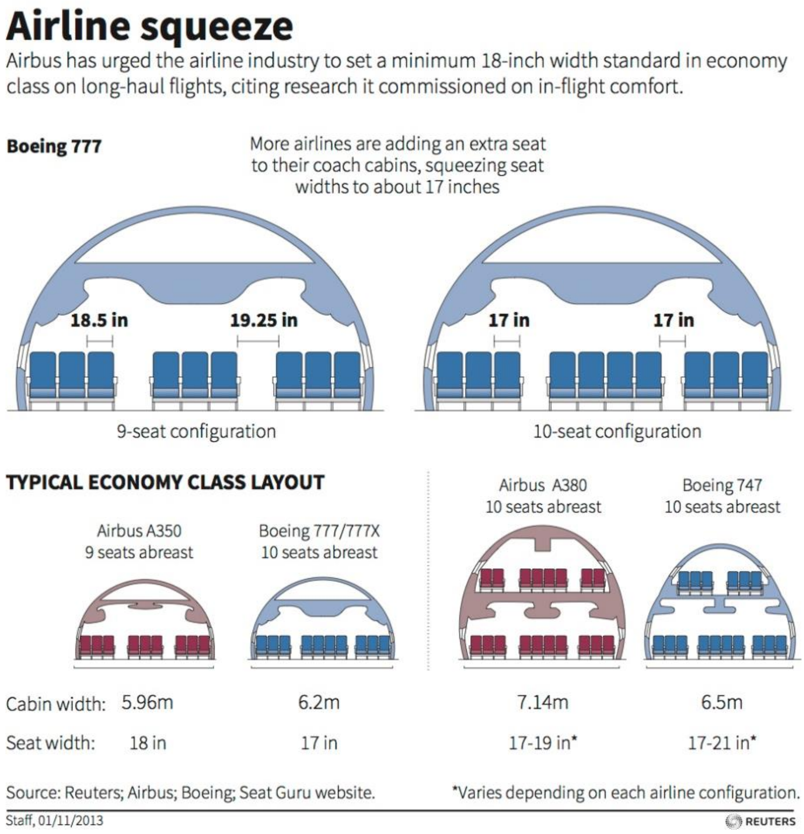

Figure 25. *Tendency of seating on commercial aviation [66].*

Among different methods we could select for this project, which are specifically designed for evaluating pure static postures, we have taken those whose properties better adapt for airplane seating and our passenger.

4.2.2.1. Rapid Upper Limb Assessment (RULA)

RULA (rapid upper limb assessment) is a survey method, which was developed for evaluating work-related upper limb disorders that are reported when an ergonomic investigation is taking place. This useful evaluation method does not have special requirements or necessities, in order to provide a fast and reliable assessment of postures and external loads that the upper limbs, the trunk or the neck experience [67].

This evaluation method was initially developed to evaluate individual workers in the garment-making industry, where operators perform a wide variety of tasks, what requires the adoption of different postures, in which there are a high number of the risk factor associated (Ibídem).

The rapid upper limb assessment employs a coding system that generates an action list, which is contained in a single page worksheet. The tasks that are included in the document cover a complete evaluation of the required body posture, the force required and the number of repetitions. When the evaluation is done, we obtain a score, which is divided in two sections: score in section A is influenced by the evaluation of the arm and wrist, while in section B scores are entered for the neck, trunk and legs. After we have collected and score the data and score for each section, the coding system which is contained in the worksheet generates a single score, which permit us to know the level of Musculoskeletal Disorders risk factors associated [68].

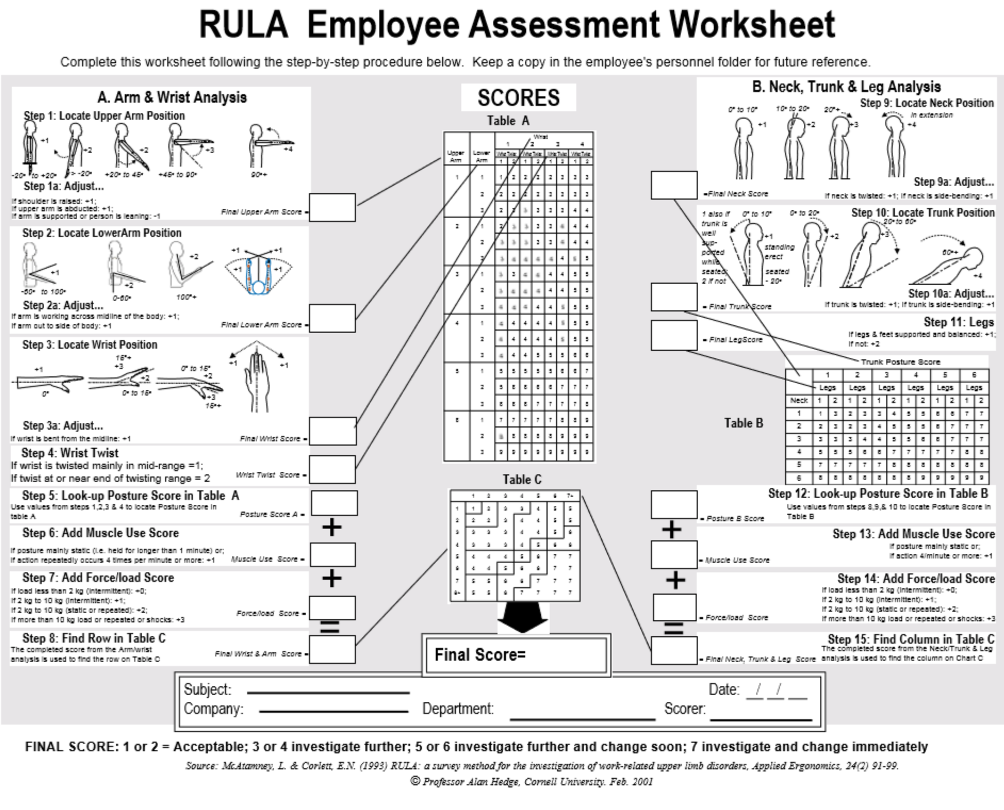

Figure 26. *RULA Employee Assessment Worksheet [69].*

RULA was designed for getting rid of expensive equipment in ergonomic evaluation methods, but not giving up that RULA was designed conceptually for being used easily. After the evaluator assigns a score for the legs, trunk, neck, wrist and upper-lower arm individually, tables on the form enable that risk factor variables are compiled. As outlined below, the result that it is generated is a single score that represent within a scale, the level of Musculoskeletal Disorder risk that our air passenger will suffer (Ibídem):

Score	Level of MSD Risk
1-2	negligible risk, no action required
3-4	low risk, change may be needed
5-6	medium risk, further investigation, change soon
6+	very high risk, implement change now

Table 2. *Level of MSD Risk using RULA [68].*

When RULA is being used for evaluating a set of tasks or a process, only one of the two sides that composes a body can be assessed at a time. After the evaluation method has finished, the evaluator can determine, by the observation and interviewing the subject of study, whether only should only be needed a complete assessment for both sides or if only a leg requires to be evaluated for that case in particular (Ibídem).

RULA reach goals that have been explained in these paragraphs and have been established four Action Level among which, depending on the final score, can be found different indications [70]:

Action level 1

A final score between 1 and 2 indicates the posture can be adopted if the person does not maintain or repeat it for longs periods of time.

Action level 2

A score of 3 or 4 denotes that further investigation and study is requires, since the necessity of changes in the posture is probable.

Action level 3

In this Action level, a score of 5 or 6 shows as a quick and complete investigation and changes are required.

Action level 4

In this case, a score of 7 denotes the immediate necessity of investigation and changes.

4.2.2.2. Rapid Entire Body Assessment (REBA)

Rapid Entire Body Assesment (REBA) is an ergonomic assessment tool which was created by Sue Highnett and Lynn McAtamney in year 2000. This method is employed for evaluating different adopted body postures with associated MSD and risk related with the task that the person is developing. REBA consist on a single page worksheet, that contains a total of thirteen steps, among which are included the evaluation of the next parts of the body and its correspondent position [71]: Neck position, trunk position, legs, upper arm position, lower arm position and wrist position.

The method allows to develop a joint analysis of the different possible positions of the body that can be taken by body regions mentioned in the previous paragraph. In addition, are also considered other factors that are critical in the final assessment of posture, such as the force used, the type of grip or type of activity that the subject of study is developing [72].

Moreover, it is possible to assess both static and dynamic postures, making it possible also consider sudden changes in posture or adoption of unstable positions (Ibídem). Nowadays, there is available a large number of studies, which support the results that the REBA method provides, so this ergonomic assessment tool is one of the most used and demanded for the analysis and evaluation of postural load [22].

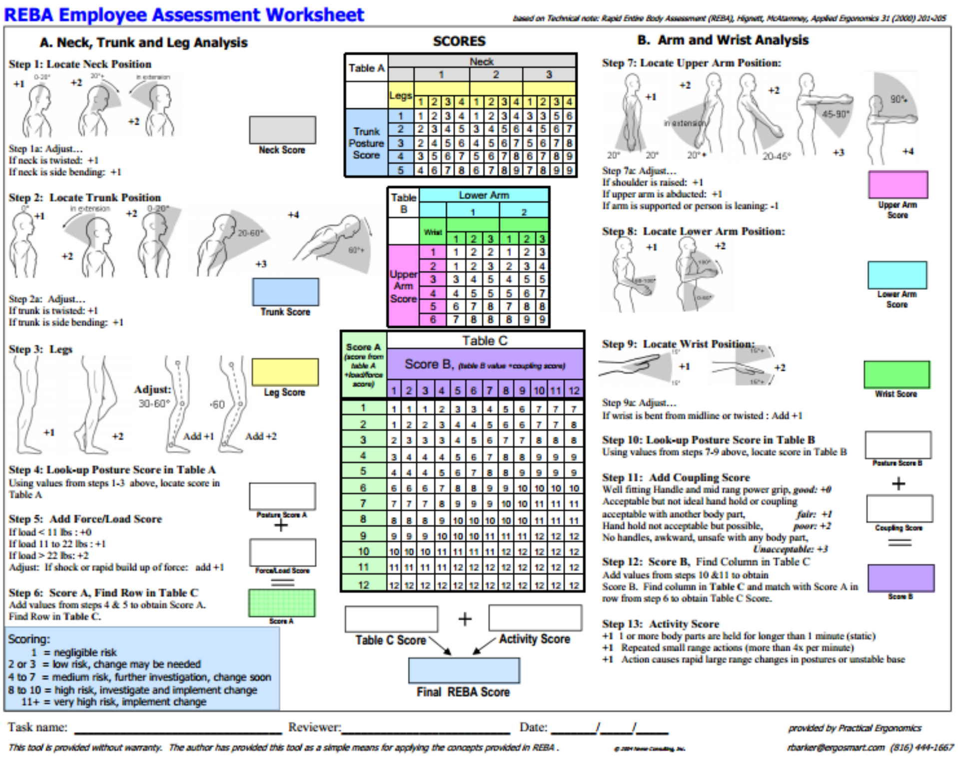

Figure 27. *REBA Employee Assessment Worksheet [73].*

The REBA was designed with the idea of providing the evaluator a simple method, which only required the worksheet and the pen for being done. After using the REBA worksheet, the evaluator will have assigned a specific score for each body region we have previously mentioned. When all these data is collected for each body region, tables on the form enable to compile the risk factor variables. This process suppose the generation of a single score that refers to the risk of suffering from a Musculoskeletal Disorder (MSD) [71]:

Score	Level of MSD Risk
1	negligible risk, no action required
2-3	low risk, change may be needed
4-7	medium risk, further investigation, change soon
8-10	high risk, investigate and implement change
11+	very high risk, implement change

Table 3. *Level of MSD Risk using REBA [71].*

Before the assessment takes place, the preparation of the process by the evaluator should consist on an interview with the worker or, in our case, the air passenger, in order to gain a full understanding of body postures that the subject of study adopts and demands. After this observation process, the evaluator will finally select what movements and postures will be evaluated. The selection criteria will be the next (Ibídem):

1) Firstly, taking into account the initial interview and observation of movements and body postures done by the evaluator, will be selected the most difficult movements and body postures.
2) Following this criteria, the evaluator will select postures maintained for a longer period of time.
3) This criteria will also include postures that suppose the exposure to high force loads.

One of the most important advantages of using REBA is that this method can be conducted quickly, what enables multiple position tasks and body postures that the subject of study adopts can be evaluated without the necessity of a significant period of time or the spending of a large sum of money. In addition to this, Rapid Entire Body Assessment only enables the right or the left side can be assessed at a time, so the evaluator should analyze and determine, after interviewing and observation process takes occurs, whether an specific assessment if needed for both sides or not. This issue should be analyzed by the individual study of each particular case in detail (Ibídem).

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Other additional advantages of using REBA are [70]:

- REBA is an ergonomic assessment method that considers risk of suffering MSDs in a wide range of tasks.
- This method incorporates in their scoring system a differentiation of the type of posture the subject adopts, since musculoskeletal risk or disorder could be caused by dynamic or static postures, for instance, or also could be caused by the action of changing or unstable postures.
- The final REBA score consist on a single mark that indicates the level of urgency we should consider to adopt corrective measures.

As previously mentioned, to the total of 144 possible combinations we must add scores, corresponding to the Rating concept for the load, the coupling and activities. This will give us the final REBA score, which will be within a range of 1 to 15, which will indicate the risk involved in developing the kind of work which has been analyzed. The score will also indicate the action levels required in each case [74].

4.2.2.3. Loading on the Upper Body Assessment (LUBA)

Although there are methods that have quantified working postures that create discomfort, many of these have not been compared with experimental data technically. This does not happen with the Loading on the Upper Body Assessment (LUBA), which is focused on specific movements that often create musculoskeletal disorders (MSDs) [36, 75].

This technique is based on new experimental data for the composite discomfort index, which is perceived for a set of articulated movements, including the hand, arm, neck and back, and the corresponding maximum time maintaining posture. In order to assess the stress of working postures, can be differentiated five categories of action to implement appropriate corrective actions. This method can be used to evaluate and redesign static working postures. Evaluators should be cautious when applying this method, especially in those tasks in which the subject is exposed to external load, a long period of time or high repeatability, because the method was developed based on the subjective discomfort perceived, regardless of these factors [75, 76].

Joint motions measured in this study		
Joint motion\Joint	Posture	
	Sitting	Standing
Wrist	Flexion	Flexion
	Extension	Extension
	Radial deviation	Radial deviation
	Ulnar deviation	Ulnar deviation
Elbow	Flexion	Flexion
	Supination	Supination
	Pronation	Pronation
Shoulder	Flexion	Flexion
	Extension	Extension
	Adduction	Adduction
	Abduction	Abduction
	Medial rotation	Medial rotation
	Lateral rotation	Lateral rotation
Neck	Flexion	Flexion
	Extension	Extension
	Rotation	Rotation
	Lateral bending	Lateral bending
Lower back	Flexion	Flexion
	Rotation	Extension
	-	Rotation
	Lateral bending	Lateral bending

Table 4. *Joint motions measured in this study [75].*

The experiment, which was developed by Kee and Karwowski in 2001, consisted on a full and exhaustive study of twenty male subjects, who participated in the experiment designed to measure perceived joint discomforts. This performance allowed the obtaining of diverse types of discomforts for distinct joint motions. The results, after being analyzed, were grouped on a postural classification scheme, based in levels of angular deviation, considering from the neutral position for each kind of joint motion. Furthermore, the postural classification scheme was divided into groups, which contain motions with the same level of discomfort, attending to statistical analysis [75].

As we previously said, the evaluator should take into consideration certain aspects when apply the Loading on the Upper Body Assessment [36, 76]:

To identify a representative working period. As with any job identification phase, will be required a previous observation of the workplace and contact the worker or workers so that they can learn about the activities performed during the workday. We must take into account several cycles of effective work, which cover both activities that are repeated over time, and those that do not.

Work breakdown into elementary operations. It consists on splitting the task into operations chronologically repeated throughout the cycle. It is recommended to establish a list of 5-10 at most elementary operations in order to avoid too detailed division that could cause unnecessary complexity in the analysis and interpretation.

Categories of action. The result of the process is the calculation of the Index of Postural Load (IPL), whose evaluation criterion postulates the maximum time that the position is maintained. With very low index results, immediate consideration is required actions and values about 10, the position is considered acceptable except in certain special postural situations, which are repeated or maintained for a long period of time.

4.2.2.3.1. Method for Movement and Gesture Assessment (MMGA)

The Method for Movement and Gesture Assessment (MMGA) started from the LUBA approach and since it was created has pretended to be a reference as a new method of classification of comfort/discomfort, considering the whole body movements [77]. The MMGA index was created by Giuseppe Andreoni in 2009, among other researchers of the INDACO department of the Politecnico di Milano.

The Method for Movement and Gesture Assessment can be defined as an innovative index, which combines the joint motion with a joint discomfort function, which depends of the body areas involved in the particular movement that is taking place. Therefore, this method quantify the ergonomics of working tasks being based on the measurement of the joint motion, using different optoelectronic tools as electro-goniometers, a stereo video-recording and specific software to complete a full data processing, in order to achieve to robust conclusions (Ibídem).

The Method for Movement and Gesture Assessment (MMGA) index incorporates these three factors as its main guidelines (Ibídem):

a) The joints motion.

b) An articular coefficient of discomfort, which is different for each joint.

c) A coefficient that estimates the weight of the ergonomic contribution of each joint to the movement.

4.2.3. Direct methods of biomechanical analysis

In this section will be explained direct methods of biomechanical analysis. All methods will be mentioned below this paragraph have the particularity of using analytical techniques by specific software and / or hardware [36, 78].

4.2.3.1. Ergo/IBV by Biomechanical Institute of Valencia

Ergo / IBV is an informatics tool that allows to assess ergonomic risks and psychosocial risks associated with the job. This ergonomic software enables biomechanical assessment by direct observation, video recording or through the application of instrumental techniques for recording position or forces. Ergo / IBV has been prepared by the Biomechanics Institute of Valencia (IBV).

This ergonomic tool is structured in several modules, which permit a complete risk assessment, covering a wide range of repetitive tasks. Below this paragraph are mention main Ergo / IBV modules [79] :

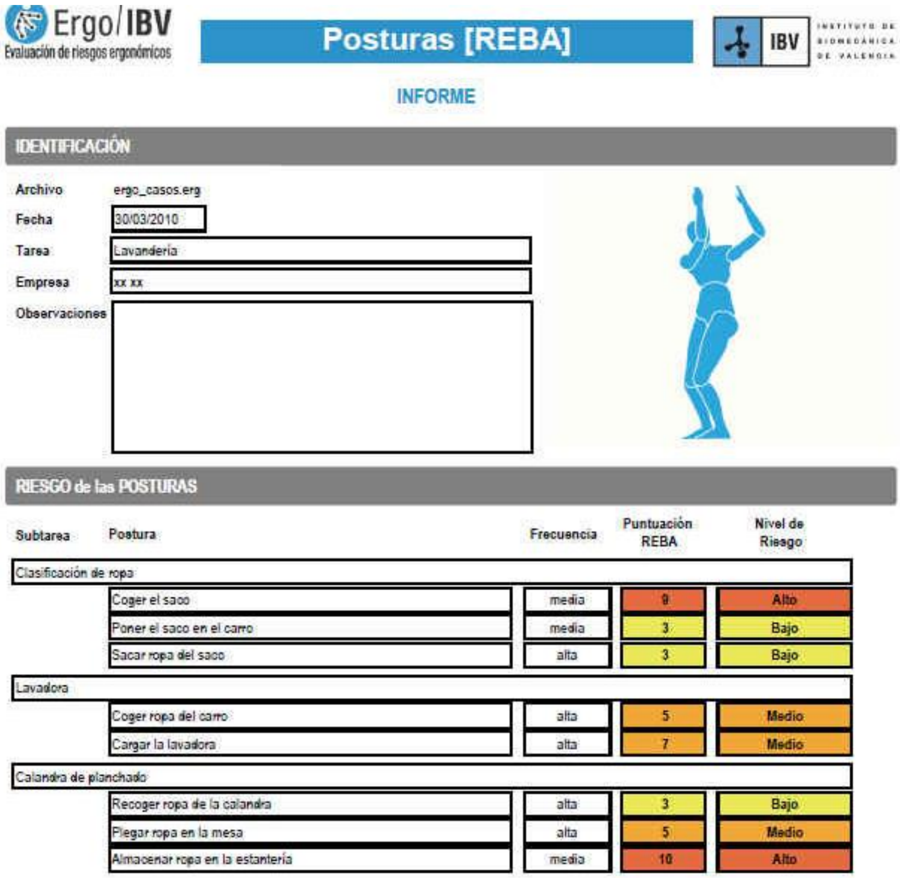
- **MMC Simple and MMC Multiple**, both modules analyze lifting tasks, transportation, pushing or pulling loads, and certain combinations of these actions. In order to analyze the tasks mentioned, this module requires certain variables associated with the task, as the weight or the position of the load. This enables to calculate an Index, which represents the risk level of the thoracolumbar back area.

- **MMC Injured**, a module used for analyzing manual lifting tasks uploads, which are made by injury workers. The purpose of this module is to minimize the risk of recurrent lumbar disorders when the worker returns to work.

- **Repetitive Tasks**, which is employed to obtain a complete analysis of task which require the realization of repetitive motions in the upper limbs. This module provide recommendations to reduce the level of risk when it is high.

- **Awkward Postures**, whose aim is to analyze those tasks which involve inadequate postures for the back, the arms and the legs. This module is based on the postural analysis Ovako Working Analysis System (OWAS) method.

- **Postures (REBA)**, in order to asses tasks which suppose the adoption of inadequate postures in the trunk, upper or lower limbs. Each posture which is assessed codes the position of each region of the body in segments, together with an associate force, a gripping type and the muscle activity that involves.



Ergo/IBV
Evaluación de riesgos ergonómicos

Posturas [REBA]

IBV INSTITUTO DE BIOMECÁNICA DE VALENCIA

INFORME

IDENTIFICACIÓN

Archivo ergo_casos.erg
Fecha 30/03/2010
Tarea Lavandería
Empresa xx xx
Observaciones

RIESGO de las POSTURAS

Subtarea	Postura	Frecuencia	Puntuación REBA	Nivel de Riesgo
Clasificación de ropa				
	Coger el saco	media	9	Alto
	Poner el saco en el carro	media	3	Bajo
	Sacar ropa del saco	alta	3	Bajo
Lavadora				
	Coger ropa del carro	alta	5	Medio
	Cargar la lavadora	alta	7	Medio
Calandra de planchado				
	Recoger ropa de la calandra	alta	3	Bajo
	Plegar ropa en la mesa	alta	5	Medio
	Almacenar ropa en la estantería	media	10	Alto

Figure 28. *Risk level of different postures using the REBA module - Ergo / IBV [79].*

At the end of the process, after it is obtained intermediate scores, final score represents the risk level of the position and level of action required to reduce the risk. This module is based on the REBA method of postural analysis.

- **UNE EN 1005-03**, this module is indicated in those tasks that perform associated forces with the use of controls or pedals.

- **Office**, which analyzes office tasks in which the worker is more than 2 hours of actual work with visual display data. This modules provide recommendations for inadequate aspects that are detected in the assessment.

4.2.3.2. 3D Static Strength Prediction Program

The 3D Static Strength Prediction Program (3DSSPP) software is a direct method of biomechanical analysis developed by the University of Michigan which enables ergonomic risk level assessment. The program is capable of predicting static strength requirements for a wide variety of job tasks and movements, such as lifts, presses, pulls or pushes. 3DSSPP software, by the incorporation of this tasks, provides a realistic simulation of different body postures. This approximate simulation includes posture data or force parameters, apart from a different anthropometry whether the subject of study is male or female [80, 81].

Biomechanical analysis is aided by the view of three dimensional human graphic illustrations and an automatic posture generation feature, whose function is to provide a full sight of the specific body posture or job task that is analyzed. As 3DSSPP indicates when it is in operation, strength is expressed as the capacity to generate a moment about a joint. The strength prediction equations are independent of the body weight of the subject of study and his or her anthropometry (Ibídem).

Figure 29. *Screen capture of the 3DSSPP application [81].*

4.2.3.3. RAMSIS

RAMSIS is a Computer Aided Design ergonomics tool, which was developed between years 1987 to 1994, as a part of a research project. The guidelines of this ergonomic tool were mainly designed and carried out at the Institute of Ergonomics at the Technische Universität München, under the supervision of Professor Heiner Bubb. When the software was available and prepared for being marketed, Human Solutions GmbH was responsible of distributing this tool, which enables ergonomic analysis and design support of products, being specially appropriated during the initial design phase [82].

Figure 30. *RAMSIS simulation of the interior of an aircraft [83].*

This ergonomic tool incorporates different modules, being highly recommended for design and redesign product in the aerospace industry, in automotive and industrial vehicles, or in the field of bus and truck, as well as construction equipment. In order to be a worldwide reference in the aerospace sector, RAMSIS incorporates a mannequin, which is highly functional in the strategy and conception phase and exactly enables the simulation of postures in the cockpit and in the air passenger's aircraft seating [83].

4.2.3.4. ErgoFellow

The ErgoFellow software was developed by FBF Sistemas in year 2009. This software incorporates seventeen ergonomic tools, which enable the evaluator to reduce occupational risk or increase productivity at the workplace, by the evaluation and the improvement of workplace conditions. ErgoFellow is a very useful tool for being employed by professionals with an ergonomic profile, researcher whose field of study is in the area of occupational safety and health, and also in an academic environment, may be used indistinctly by professors, docents or students [84].

ErgoFellow has the following ergonomic tools (Ibídem):

- NIOSH (Revised Lifting Equation)
- OWAS (Ovaco Working Posture Analysing System)
- RULA (Rapid Upper Limb Assessment)
- REBA (Rapid Entire Body Assessment)
- SUZZANE RODGERS
- MOORE E GARG (The Strain Index)
- DISCOMFORT QUESTIONNAIRE
- QEC (Quick Exposure Check)
- LEHMANN
- IMAGE ANALYSIS
- VIDEO ANALYSIS
- ANTHROPOMETRY
- CALCULATION OF FORCE
- PPE (Personal Protective Equipment)
- HEAT STRESS
- NOISE EXPOSURE (OSHA)
- TYPING EVALUATION

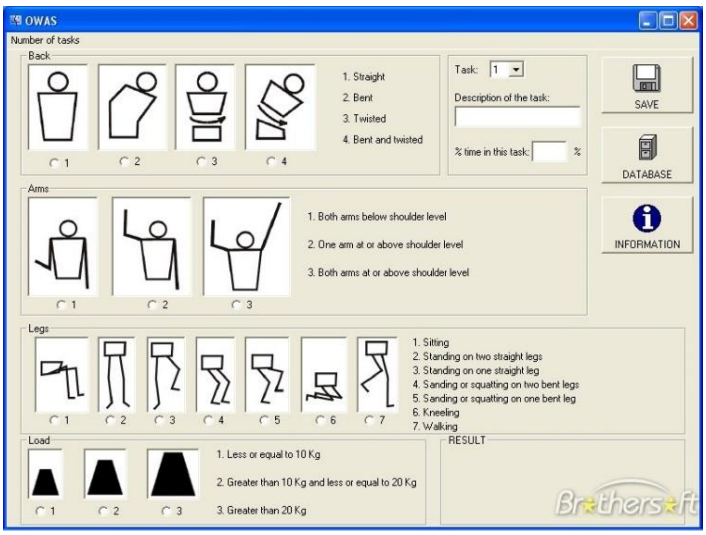


Figure 31. *Screen capture of the ErgoFellow application [84].*

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4.2.3.5. ErgoIntelligence Upper Extremity Assessment (UEA)

ErgoIntelligence Upper Extremity Assesment (UEA) is an ergonomic job analysis tool, developed by NexGen Ergonomics, which was founded in Canada in 1995. This company is responsible of providing a wide variety of products and systems for ergonomic and biomechanical assessment and job-analysis, besides research and design in these fields [70].

NexGen Ergonomics product line includes UEA, a specific software for ergonomic job analysis which incorporates ergonomic assessment, facilitating the use of different methods of direct observation, such as RULA, REBA, Strain Index (SI), Occupational Repetitive Actions Index, Cumulative Trauma Disorders Risk Index or ACGIH HAL (Ibídem).

The UEA assesses the risk level of developing cumulative trauma disorder in the upper limbs, including the hands, the wrists, the lower and upper arms, the neck and the trunk. Therefore, this specific software enables assessing concrete and repetitive auxiliary tasks that an air passenger can experience during the air flight. Some of them are the action of collocating the hand luggage in its specific location, along the aisle and above the seats, or using the laptop on the tray that the front seat incorporates, while the passenger is sat.

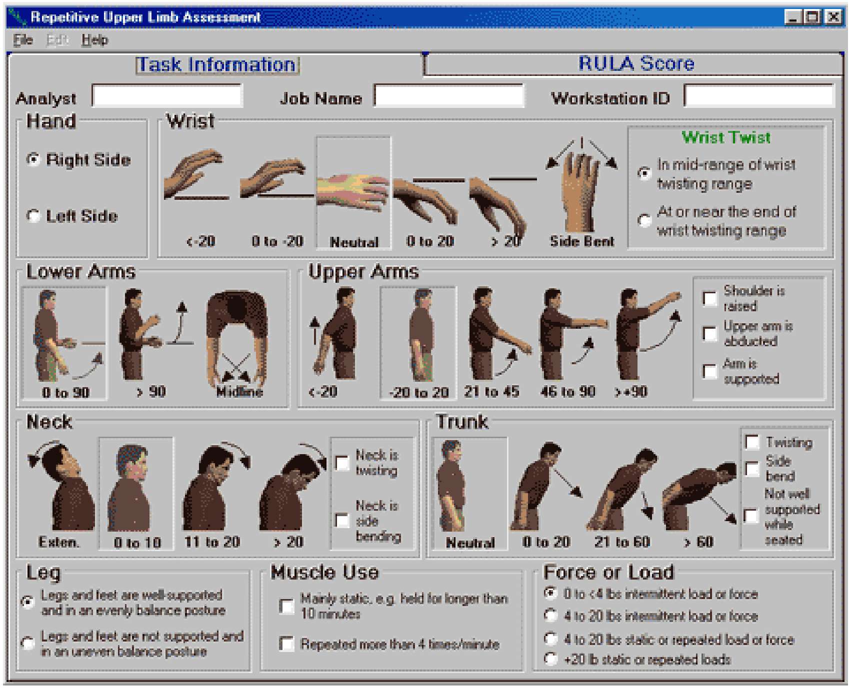

Figure 32. *ErgoIntelligence Upper Extremity Assessment [70].*

CHAPTER 5: METHODS EMPLOYED

The importance manufacturers and companies are conferring to achieve an optimal working environment in boosting productivity and reducing absenteeism rates has given rise to the field of ergonomics and its principles are integrated as a primary element when a product is in the design phase and also in the product life cycle [85].

In the present bachelor thesis is employed a packet of ergonomics tools, in order to understand and analyze potential risks that any air passenger may experiment when he or she adopts different seated postures on his or her aircraft seat.

In order to differentiate steps are given during the present postural risk assessment, project methodology is divided in three different phases that can be observed in the table below. Firstly, the methodology includes the description and definition of a postural catalogue that have been selected attending to common processes and postural activities can be developed in commercial aviation aircraft seating. The second phase includes direct observation methods have been considered in the present study. After that, it follows a complete analysis of each seated position by direct methods that include specific software and, when results are obtained, they are compared and analyzed. The software tools that have been incorporated to develop the postural study are ERGO/IBV and 3DSSPP. Finally, for those postures identified as a potential risk for the passenger, it will be applied the FMEA (Failure Modes and Effects Analysis) method, in order to identify the most critical parts of processes.

Phase 1. Processes and activities definition	*- Group (a): Neutral postures* *- Group (b): Laptop/iPad postures* *- Group (c): Reading positions* *- Group (d): Sleeping postures* *- Group (e): Other postures*
Phase 2. Direct observation methods	*-REBA* *-The National Institute for Occupational Safety and Health Method "NIOSH"*
Direct methods for biomechanical analysis	*-ERGO/IBV* *-3DSSPP*
Phase 3. Failure Modes and Effects Analysis (FMEA)	*-FMEA spreadsheet*

Table 5. *Description of followed strategy in the aircraft seating postures risk assessment.*

5.1. Normalization of methods employed

Methods employed for postural analysis, for both direct observation methods and biomechanical software tools, do not maintain the same scoring system. This makes necessary to equate them by a revision and a normalization in the score of each method.

The normalization system have been followed in the present thesis, preserves [86] scoring criteria. This criteria differentiates among three possible levels of ergonomic risk: the first option indicates the risk level does not exist or it is negligible (it is not required an intervention in terms of ergonomics), a moderated risk marks it is necessary to implement modifications in a short/medium period of time and, lastly, a high level of ergonomic risk (this risk level indicates an urgent intervention is required).

In this way, it will be conducted a comparison and standardization among the scoring system of each selected method in the final results section. The pretension of this standardization is to proceed to make equivalent the results calculated and to permit a better understanding of the magnitude of ergonomic risk obtain in each method. Therefore, if the score obtained is 0, it is not necessary to perform changes over the activity. In contrast, whether the score is 1, it is necessary to conduct modifications in the postural activity in a short/medium time period. Finally, a score of 2, the highest possible, indicates the necessity of implementing urgent modifications, in order to reduce the potential risk.

Method	Method scoring system	Action and risk level	Score after standardization procedure
REBA	1 2-3 4-7 8-10 11-15	0 (negligible risk) 1 (low risk) 2 (medium risk) 3 (high risk) 4 (very high risk)	0 0 1 2 2
NIOSH	<=1 1-3 =>3	Low risk Medium risk High risk	0 1 2
IBV	Level 1 Level 2 Level 3 Level 4	Low risk Medium risk High risk Very high risk	0 1 2 2
3DSSPP	Acceptable Not acceptable	Low risk High risk	0 2
FMEA	1-100 101-432 433-1000	Low risk Medium risk High risk	0 1 2

Table 6. *Conversion table of risk final scores, depending of method employed.*

5.2. Phase 1. Processes and activities definition

In order to recognize and assess processes and activities air passengers experiment when they are seated inside an aircraft, it has previously been defined a group of reference postures. These postures have been selected attending to the wide variety of existing postures in the aircraft seating sector.

The selected postures have been chosen attending to different academic sources. The main source of information have been scientific articles related to the ergonomics field. All these contributions are published and available in international seminars, conferences and congresses, as well as in prestigious scientific journals. Research documents such as bachelor, master and doctoral thesis have also been considered in postural definition.

The seated positions which have been selected under a period of examination are:

- Group (a): Neutral postures. This group contains postures that are supposed to provide neutral positioning to the body [41]:

- Upright sitting posture.
- Declined sitting posture.
- Reclined sitting posture.

- Group (b): Laptop/iPad postures. The adoption of these seated positions requires to pay attention especially on head/neck and hand/wrist postures. These parts of the body previously mentioned are highly exposed to develop MSDs while using electronic devices [52]. Laptop and iPad postures that have been identified are the next:

- Laptop posture (laptop is on a surface in front of the passenger).
- Laptop posture (the laptop is leant on the passenger’s legs).
- iPad posture (the tablet is held on the palm of the hand).

- Group (c): Reading positions. The action of reading a document, also whether the document consist on a book or a journal, represents a postural challenge [56]. Therefore, this type of seated positions must be considered for the postural analysis, as well as laptop and iPad postures:

- Reading position (flexed arms at the shoulder joint).
- Reading position (supporting the arm that holds the book).

- Group (d): Sleeping postures. Long-range travels increment the time period air passengers spend on their aircraft seats. This fact suppose a reduction of comfort level while the travel is taking place, what favours the passenger sleeps during the trip [3].

Although sleeping postures have been previously grouped in four general sitting postures, a reunification in six types of reference postures enables a better understanding when positions are analyzed by computer software:

- Neutral position.
- Slide down position.
- Sideway position.
- Sideway position (with hands).
- Turned torso.
- Turned torso (head perpendicular to back rest).

• Group (e): Other postures. In addition to this common postural activities, other two additional seated positions will be subject of study:

- Baby posture.
- Eating posture.

5.3. Phase 2. Direct observation methods and direct methods for biomechanical analysis

The results of this thesis consist on a comparative study among sitting postures have previously been identified and defined. In order to achieve this, the direct observation method have mainly been selected among the extensive bibliography has been compiled in section 4.2.2, attending to the thesis necessities, is the Rapid Entire Body Assessment (REBA).

The REBA method enables the evaluator to conduct a joint analysis of the different possible positions of the body that can be taken by body segments. In addition, are also considered other factors that are critical in the posture final assessment, such as the force used, the type of grip or type of activity that the subject of study is developing [72].

In addition to the REBA method, in baby posture, which is classified in group (e), the passenger experiments load-lifting and pressure with a considerable weight when the passenger holds the baby. For this particular case, it will be considered the limits of the NIOSH equation, whose field of actuation is thought for load-lifting, manual load handling and load transport [81].

Risk factors	Direct observation methods
Cramped and static postures	*Rapid Entire Body Assessment ''REBA''*
Load-lifting, manual load handling and load transport	*The National Institute for Occupational Safety and Health Method "NIOSH''*

Table 7. *Risk factors and direct observation methods applied.*

Software ERGO/IBV

The employment of this ergonomic software contributes to the goal of conducting the investigation at the minimum possible cost, what has been possible due to the ten days trial period the tool incorporates.

ERGO/IBV offers a wide variety of ergonomic assessment methods: REBA, OWAS, OCRA, IBV or NIOSH, amongst others. The requirements of the present investigation make ERGO/IBV-REBA module the most appropriated to assess the ergonomic risk level that air travellers experiment on a plane seat. Map of main body regions that are exposed to suffer an ergonomic impact, caused by an inadequate posture includes the trunk, the neck and upper/lower limbs, whose risk level will be assessed with the REBA score system.

Software 3DSSPP

The 3DSSPP is an ergonomic tool that enables manual materials and handling tasks assessment. This software is highly employed by engineers, ergonomist and researchers to evaluate and design jobs. The present project will establish the conformance of different postures previously defined. The novelty software 3DSSPP incorporates is the possibility to input anthropometric data, as well as the option to obtain the value of different moments and forces which has been calculated by the ergonomic tool automatically, instead of being necessary to perform a manual calculation [87].

The use of this ergonomic tool has been possible thanks to the courtesy of University of Michigan, since software 3DSSPP includes a 14 days trial version in the software ergonomic tool downloading.

5.4. Phase 3. Failure Modes and Effects Analysis (FMEA) Tool

According to the Institute for Healthcare Improvements (IHI), ''the Failure Modes and Effects Analysis (FMEA) is a systematic, proactive method for evaluating a process to identify where and how it might fail and to assess the relative impact of different failures, in order to identify the parts of the process that are most in need of change''.

FMEA was first applied by the aerospace industry in the 60s, and even received an American military specification MIL- STD16291 entitled "Procedures for the analysis of failure mode, effects and criticality" [88].

It is fundamental to have a good knowledge of certain terminology, which results basic when analyzing failure and its effects (Ibídem):

- *Severity*, this concept makes reference to the importance that the effect produce on costumer requirements.

- *Occurrence*, this term refers to the frequency and regularity a given cause occurs and originates failure modes.

- *Detection*, the ability to detect a given cause by the current control scheme.

The rating scales allow the classification of these parameters among a score of 1-10, as can be observed in the following tables:

Rating	Description	Definition (Severity of Effect)
10	Dangerously high	Failure could injure the customer or an employee.
9	Extremely high	Failure would create noncompliance with federal regulations.
8	Very high	Failure renders the unit inoperable or unfit for use.
7	High	Failure causes a high degree of customer dissatisfaction.
6	Moderate	Failure results in a subsystem or partial malfunction of the product.
5	Low	Failure creates enough of a performance loss to cause the customer to complain.
4	Very Low	Failure can be overcome with modifications to the customer's process or product, but there is minor performance loss.
3	Minor	Failure would create a minor nuisance to the customer, but the customer can overcome it without performance loss.
2	Very Minor	Failure may not be readily apparent to the customer, but would have minor effects on the customer's process or product.
1	None	Failure would not be noticeable to the customer and would not affect the customer's process or product.

Table 8. *Severity Rating Scale [89].*

Rating	Description	Potential Failure Rate
10	**Very High:** Failure is almost inevitable.	More than one occurrence per day or a probability of more than three occurrences in 10 events.
9	**High:** Failures occur almost as often as not.	One occurrence every three to four days or a probability of three occurrences in 10 events.
8	**High**: Repeated failures.	One occurrence per week or a probability of 5 occurrences in 100 events.
7	**High**: Failures occur often.	One occurrence every month or one occurrence in 100 events.
6	**Moderately High:** Frequent failures.	One occurrence every three months or three occurrences in 1,000 events.
5	**Moderate:** Occasional failures.	One occurrence every six months to one year or five occurrences in 10,000 events.
4	**Moderately Low**: Infrequent failures.	One occurrence per year or six occurrences in 100,000 events.
3	**Low:** Relatively few failures.	One occurrence every one to three years or six occurrences in ten million events.
2	**Low:** Failures are few and far between.	One occurrence every three to five years or 2 occurrences in one billion events.
1	**Remote:** Failure is unlikely.	One occurrence in greater than five years or less than two occurrences in one billion events.

Table 9. *Occurrence Rating Scale [89].*

Rating	Description	Definition
10	Absolute Uncertainty	The product is not inspected or the defect caused by failure is not detectable.
9	Very Remote	Product is sampled, inspected, and released based on Acceptable Quality Level (AQL) sampling plans.
8	Remote	Product is accepted based on no defectives in a sample.
7	Very Low	Product is 100% manually inspected in the process.
6	Low	Product is 100% manually inspected using go/no-go or other mistake-proofing gauges.
5	Moderate	Some Statistical Process Control (SPC) is used in process and product is final inspected off-line.
4	Moderately High	SPC is used and there is immediate reaction to out-of-control conditions.
3	High	An effective SPC program is in place.
2	Very High	All product is 100% automatically inspected.
1	Almost Certain	The defect is obvious or there is 100% automatic inspection with regular calibration and preventive maintenance of the inspection equipment.

Table 10. *Detection Rating Scale [89].*

When severity, occurrence and detection have been assessed, the next step is to calculate the risk-priority-number (RPN). The RPN is defined as the product of the Severity, the Occurrence and Detection of a failure [90].

Severity x Occurrence x Detection = RPN

The RPN values are ranked between 1 and 1000, in order to know in detail those failures which are exposed to a higher risk for correction. This factor must be calculated individually for each cause of failure. The RPN indicates a relative probability of a failure mode and, as higher as the number was, the failure mode will be higher [91].

According to the next table, a RPN ≥ 432 should be considered as a high risk index, so urgent measures to minimize or to eliminate the potential risk are required (Ibídem):

Risk Level	RPN interval
Low risk	1 - 100
Medium risk	101 - 432
High risk	433 - 1000

Table 11. *Risk levels based on RPN [91].*

Therefore, the FMEA method will be applied in those sitting postures have been identified in the present project as a potential risk for the passenger. This means an air passenger, with the adoption of a determined body posture, is exposed at a high risk of developing a MSD.

Postural activities have been established in the thesis have previously been tested under direct methods for biomechanical analysis. In case the diagnosis evidence a sufficiently high level of MSD risk, the Failure Modes and Effects Analysis will be responsible of evaluating in detail the critical points of the process that require to implement changes.

CHAPTER 6: RESULTS

In this chapter it will be treated the results of the postural catalogue ergonomic risk assessment. Direct methods for biomechanical analysis employed in aircraft seating postures assessment are:

ERGO/IBV, what have been possible due to the ten days trial period the tool incorporates.

3DSSPP, thanks to the courtesy of University of Michigan, which also includes a 14 days trial version in the software ergonomic tool downloading.

6.1. Software ERGO/IBV V14

The REBA module is selected in ERGO/IBV tool to conduct the analysis of all possible aircraft seating postures. At the end of this document, in appendix can be observed in detail introduced parameters, that includes body segments angle, load supported, grip type, kind of activity developed (in this thesis it will be always considered the development of static activities). At the end of the analysis can be found the final REBA score for each posture, with the indication of the risk level.

Posture	REBA score	Risk level	Standardized score
Upright sitting posture	2	Low risk	0
Declined sitting posture	2	Low risk	0
Reclined sitting posture	3	Low risk	0
Laptop posture (laptop positioned on a surface in front of the passenger)	2	Low risk	0
Laptop posture (laptop leant on the passenger's legs)	4	Medium risk	1
iPad posture	3	Low risk	0
Reading position (with flexed arms at the shoulder joint)	2	Low risk	0
Reading position (supporting the arm that holds the book)	3	Low risk	0
Sleeping posture – Neutral position	2	Low risk	0
Sleeping posture – Slide down	3	Low risk	0
Sleeping posture – Sideway position	5	Medium risk	1
Sleeping posture – Sideway position (with hands)	6	Medium risk	1
Sleeping posture – Turned torso	6	Medium risk	1
Sleeping posture – Turned torso (head perpendicular to back rest)	4	Medium risk	1
Baby posture	5	Medium risk	1
Eating posture	6	Medium risk	1

Table 12. *Results in the software ERGO/IBV application.*

6.2. Software 3DSSPP

3DSSPP is selected application to complete an auxiliary baby posture assessment. It is considered and appropriated biomechanical tool to analyze again whether this posture overcomes ergonomic requirements, since the baby weight is the highest load that the postural catalogue defined in this thesis incorporates. In addition, the fact that software 3DSSPP enables for users to input anthropometric data, makes the opportunity to consider representative population samples highly recommendable [87].

Consequently, it can be found a specification of the task-input, which results necessary to achieve a complete understanding of obtained results:

Task-input

-*3D static mode*, since all seated postures subject of study have been analyzed following static working conditions.

-*Earth gravity* is the gravitational force considered for ergonomic risk assessment. The value of the earth gravity is 9,807 $\frac{m}{s^2}$.

-*Support selection*. In order to consider real aircraft seating dimensions, back rest center height above rest has been taken from Ryanair aircraft seat dimensions that are available on Ryanair website. This case can be observed in the next screen shot:

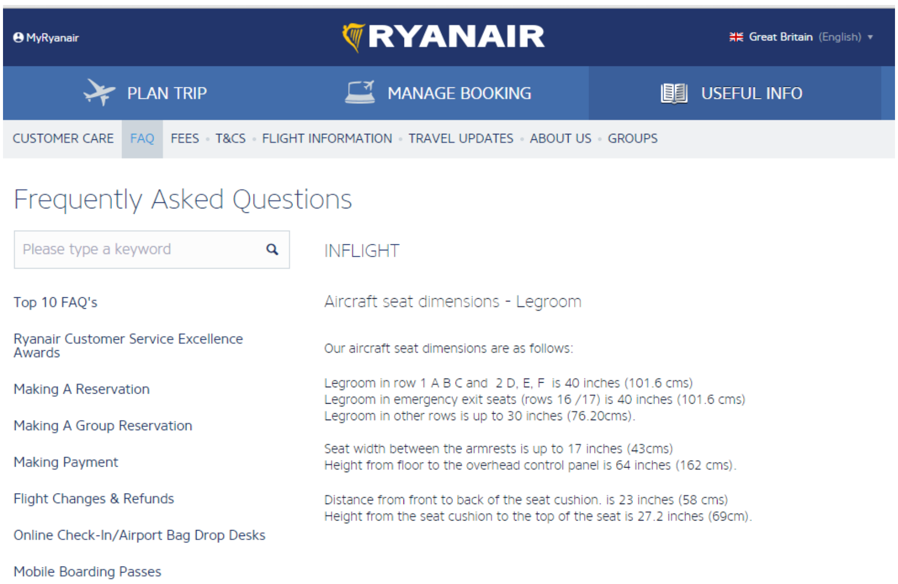

Figure 33. *Ryanair aircraft seat dimensions [92].*

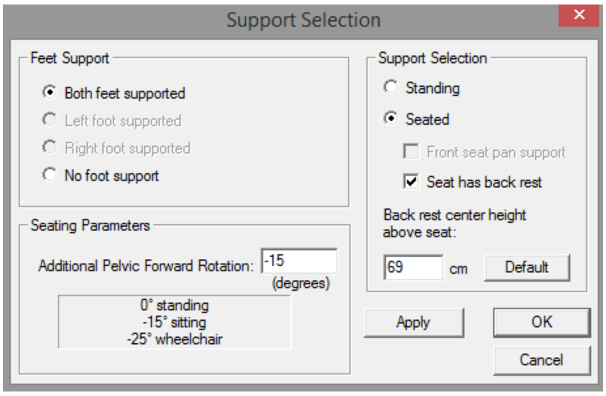

Figure 34. *Screen shot of support parameters.*

-*Body segments angle*, this option enables definition of all body regions only with the necessity of establishing the angle of different body segments.

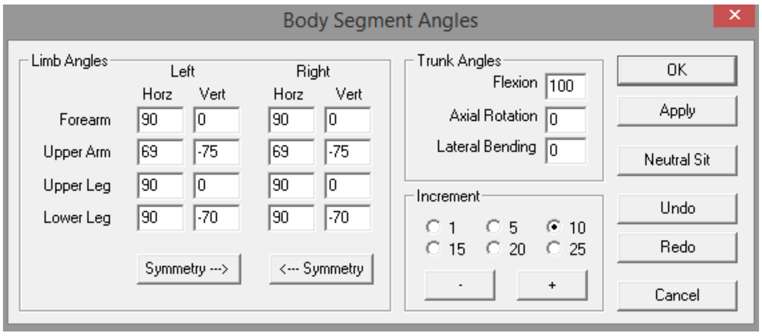

Figure 35. *Screen shot of body segment angles definition.*

-*Load supported*, in this case it corresponds with the weight of the baby, and the hands are the part of the body that sustains the load. For this case, it have been considered a load of 49.03 N on each hand, which is equivalent to a total mass of 10 kg (F=m x g).

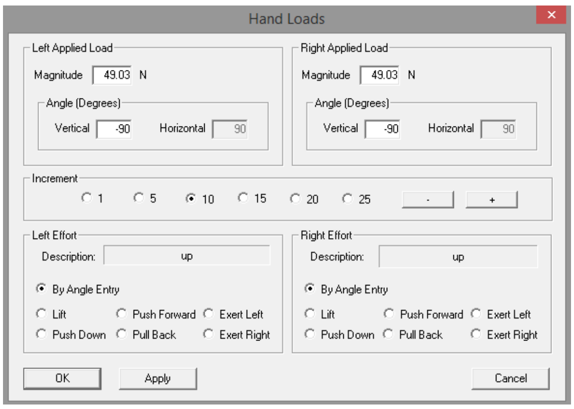

Figure 36. *Screen shot of hands loads.*

Baby posture results

After task-input data introduction, 3DSSPP software reflects the information initially introduced and it is responsible to analyze whether baby posture is acceptable or not in terms of ergonomics.

One of 3DSSPP possibilities is anthropometric data consideration of different percentiles. This option enables a more detailed analysis in the ergonomics of the posture, since it can be simulated how would interact a male or female subject at the 50th and 75th percentile for height and weight.

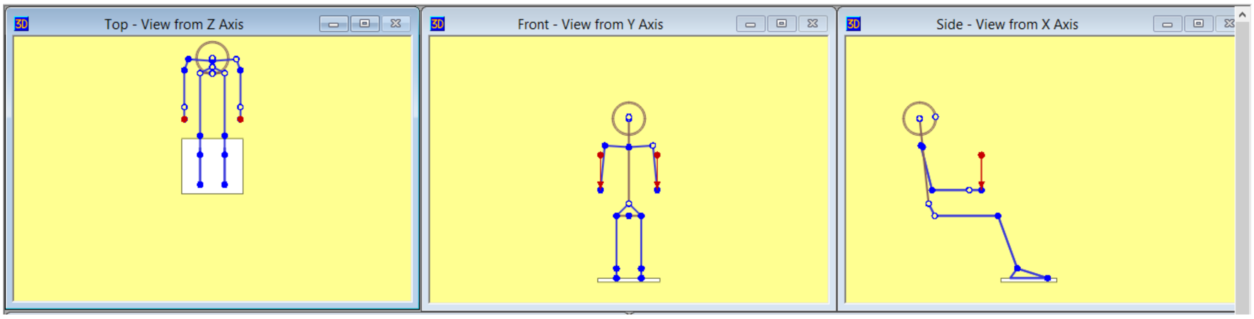

Figure 37. *Screen shot of baby posture definition, where can be observed body segments angle and hand loads supported.*

Posture and anthropometric data	3DSSPP balance	Risk level	Standardized score
Baby posture / Male Percentile 50th	2	Acceptable	0
Baby posture / Male Percentile 95th	2	Acceptable	0
Baby posture / Female Percentile 50th	3	Acceptable	0
Baby posture / Female Percentile 95th	2	Acceptable	0

Table 13. *Results in the software 3DSSPP application.*

Case 1. Male percentile 50th

This case considers anthropometry of a male subject at the 50th percentile corresponds with a man who has a height of 175.1 cm and a weight of 83.9 kg.

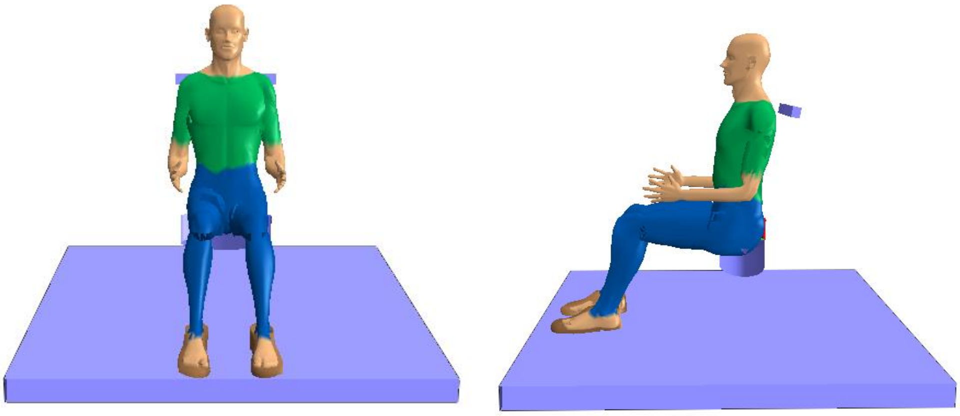

Figure 38. *Screen shot of male subject and support that supplies the plane seat, with the configuration previously introduced in task-input.*

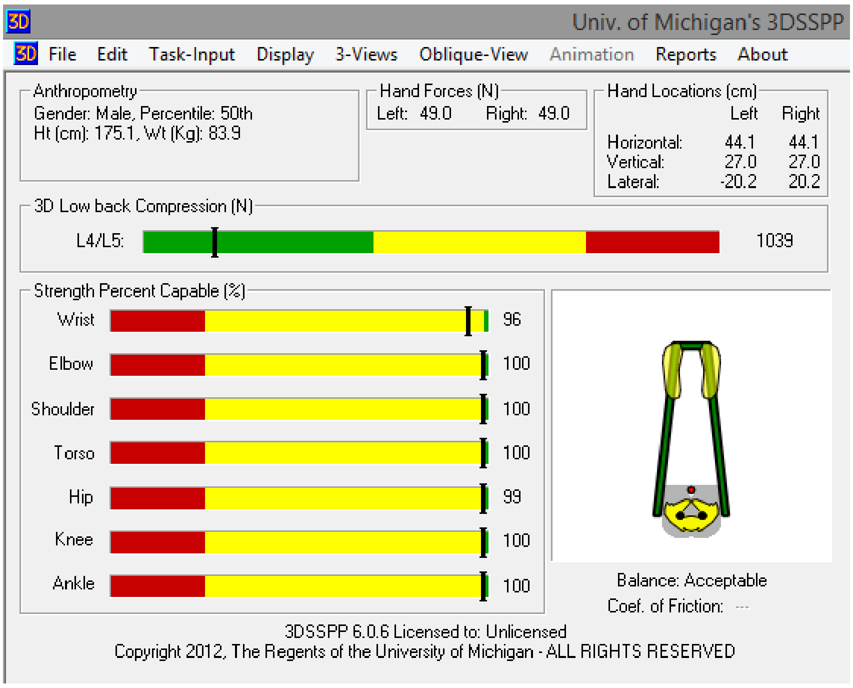

Figure 39. *Screen shot of male percentile 50th final results.*

Case 2. Male percentile 95th

This case considers anthropometry of a male subject at the 95th percentile corresponds with a man who has a height of 187.9 cm and a weight of 125.2 kg.

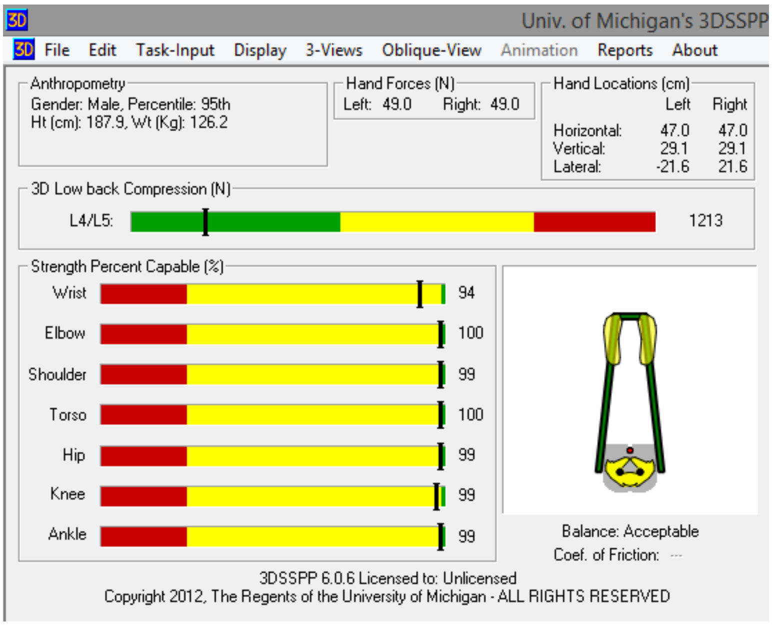

Figure 40. *Screen shot of male percentile 95th final results.*

Case 3. Female percentile 50th

This case considers anthropometry of a female subject at the 50th percentile corresponds with a man who has a height of 161.6 cm and a weight of 72.7 kg.

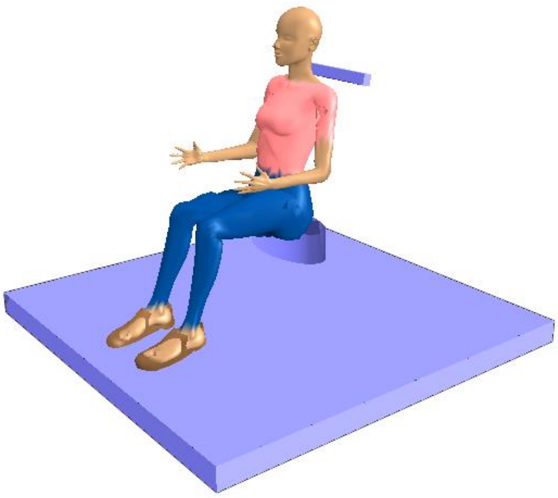

Figure 41. *Screen shot of female subject and support that supplies the plane seat, with the configuration previously introduced in task-input.*

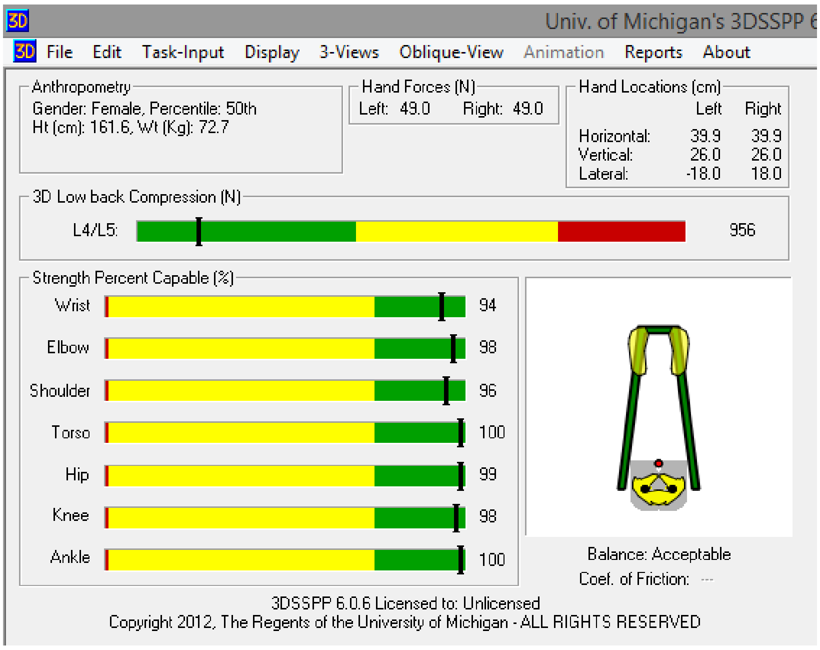

Figure 42. *Screen shot of female percentile 50th final results.*

Case 4. Female percentile 95th

This case considers anthropometry of a female subject at the 95th percentile corresponds with a man who has a height of 172.7 cm and a weight of 115 kg.

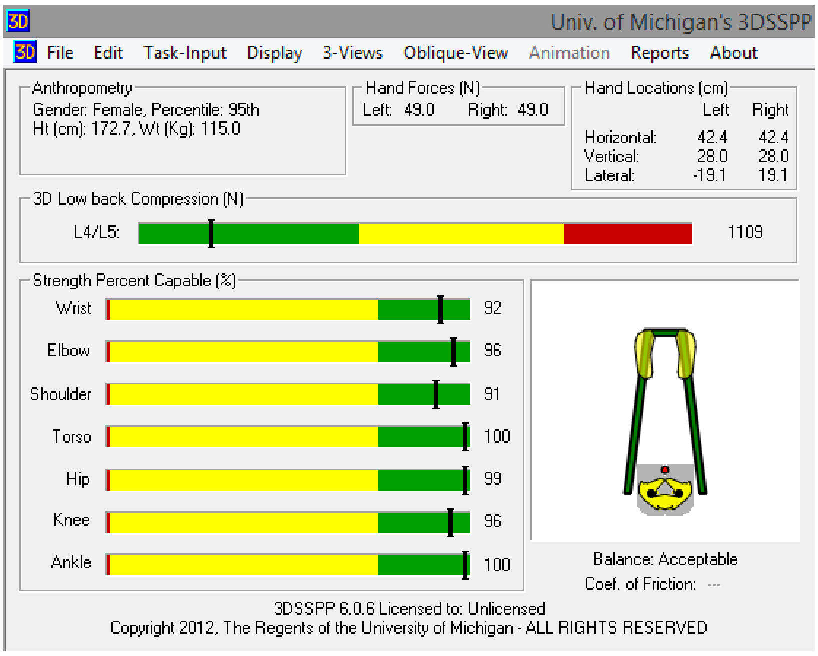

Figure 43. *Screen shot of female percentile 95th final results.*

6.3. Failure Modes and Effects Analysis (FMEA)

Finally, the FMEA has been applied in those postures whose ergonomic risk level, previously assessed with direct observations methods, is sufficiently high to be considered a potential risk for the passenger, in terms of commodity and ergonomics. This means an air passenger, with the adoption of a determined body posture, is exposed at a medium/high risk of developing a MSD.

Therefore, in case the diagnosis evidence a sufficiently high level of MSD risk, the Failure Modes and Effects Analysis will be responsible of prioritizing critical postures of the process that require to implement changes.

Operation	SEV	DET	PROB	RPN	Priority Risk Index
Laptop posture (laptop leant on the passenger's legs)	2	8	5	80	Low
Sleeping Posture – Sideway position	2	7	7	98	Low
Sleeping Posture – Sideway position (with hands)	2	7	6	84	Low
Sleeping torso – Turned torso	3	8	5	120	Medium
Sleeping torso – Turned torso (head perpendicular to the back rest)	3	8	5	120	Medium
Baby Posture	3	8	4	96	Low
Eating Posture	2	8	5	80	Low

Table 14. *Results of the FMEA application.*

6.4. Cabin Layout & Comfort

The interior of airplane fuselage offers different possibilities when it is being designed and defined passenger's cabin layout, during the aircraft manufacturing process. The decision of selecting among different layouts has a direct impact in terms of ergonomics, since this decision directly affects the width of the aircraft seats and other dimensional aspects, such as the seat pitch [93].

Commercial airplanes can be divided in two main types of aircrafts:

- Single aisle aircrafts, whose main characteristic is airline seats are distributed along a single aisle. Also known as narrow-body aircrafts, the A320 family is one of most demanded models in this sphere. Till the month of April, there are currently orders for 7679 units, since the start of the program [94]. Main dimensions and key data can be found below this paragraph:

Figure 44. *Key figures of the founding member of Airbus' single-aisle Family, the A320 [94].*

- Wide-body aircrafts, in contrast, incorporates twin aisles and are usually configured with multiple travel classes, what provide airlines a highest level of flexibility, when deciding the plane layout and how to make flights profitable. Airbus A350 XWB is one of major novelties in this area, offering a typical passenger capacity of 315 seats [95].

Figure 45. *Key figures of the Airbus A350 XWB [95].*

A320 family seating configuration offers the possibility of choosing between travelling in Premium or Economy class, what modifies passenger's flight conditions considerably [94]:

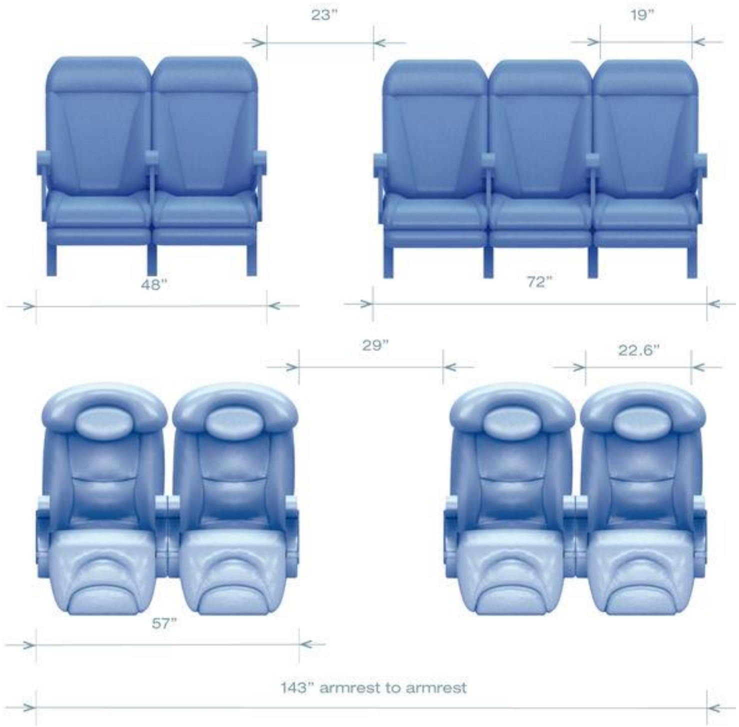

Figure 46. *A320 family seating configuration – Premium [94].*

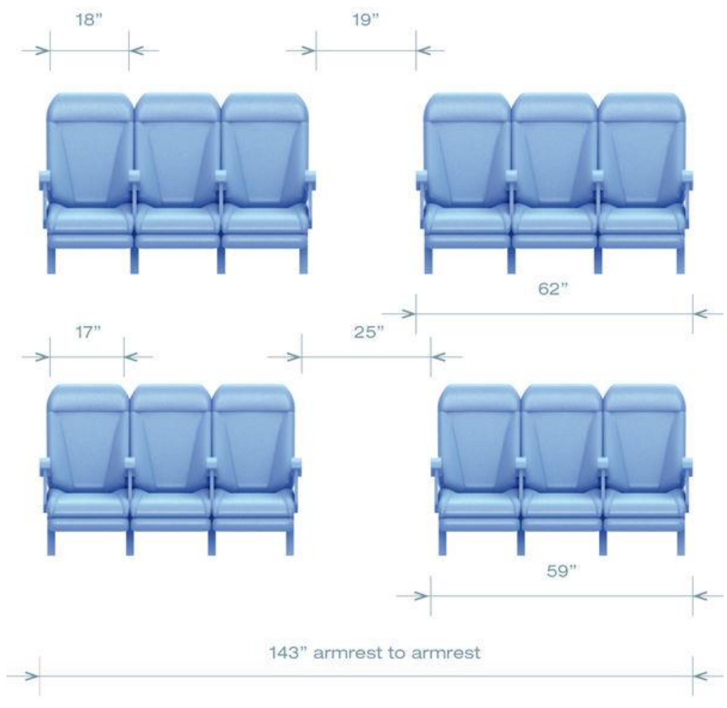

Figure 47. *A320 family seating configuration – Economy class [94].*

A350 XWB family offers a wide range of possibilities when selecting cabin layout, including arrangements at up to ten abreast seating [95]:

Figure 48. *A350 XWB 6 abreast – Business Class and 7 abreast – Regional Business cabin layout [95].*

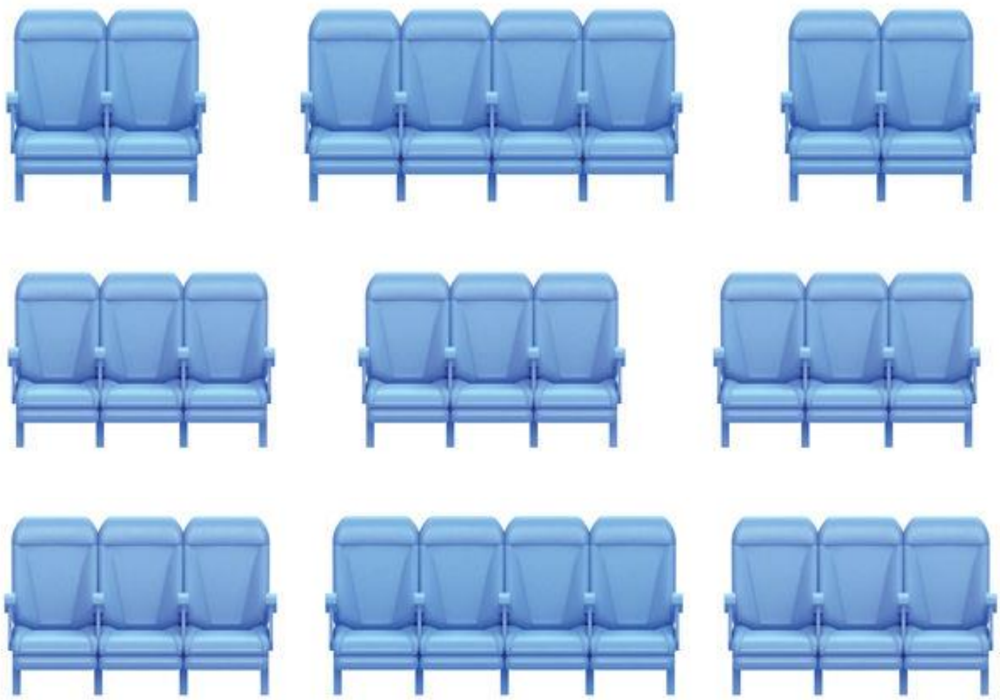

Figure 49. *A350 XWB 8 abreast – Premium economy, 9 abreast – Standard Economy and 10 abreast - Highly Efficient [95].*

As can be observed, the high level of variability in cabin layout makes necessary a clear regulation, in order to reference the minimum space between seat rows. At this respect CAA, the British Civil Aviation Authority, established in year 2003 a minimum seat pitch of 26 inches (66 cm) between passenger's backrest and front seat backrest [93].

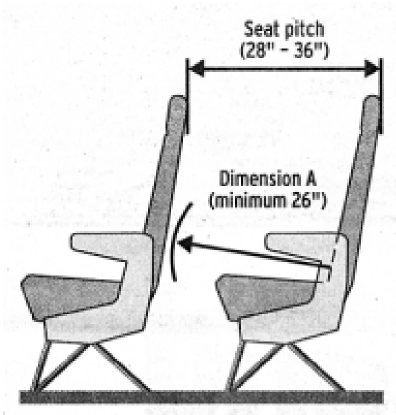

Figure 50. *British Civil Aviation Authority establishes a minimum seat pitch of 26 inches in 2003 [96].*

Other important dimensional factor that affects air passenger's ergonomics is the seat width, since this value defines the spaciousness and operability of passenger's upper limbs. This measure is considered between the interior parts of both armrests.

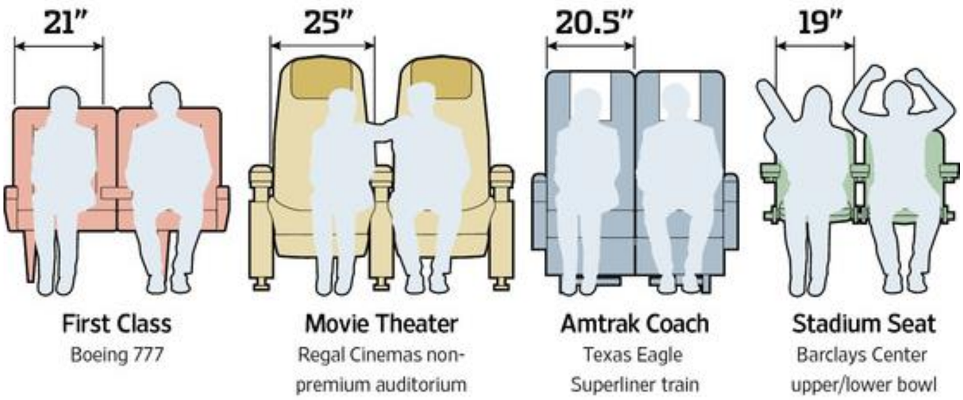

Figure 51. *Seat width comparison among First Class plane seats and different public seating options [97].*

Therefore, the decision of defining the seat pitch/width and class sections that compounds the cabin are responsibility of the airline. This decision, combined with the passenger's seat choice and the positions adopted during the flight will define the passenger's ergonomic possibilities to maintain neutral body postures. The maintenance of these neutral body postures will considerably help to reduce the development of MSDs [41].

6.5. Germanwings plane crash in Alps

On 24 March, 2015, an Airbus A320 operated by Germanwings, a low-cost company property of Lufthansa, was crashed after a constant descent in the French Alps by the co-pilot of the aircraft, Andreas Lubitz. Lubitz, who had previously been treated for suicidal tendencies, was declared unfit to work only a few weeks before he deliberately decided to cause this aerial tragedy [98].

The accident occurred while the pilot had left the cockpit momentarily to go to the aircraft lavatory. Circumstances have involved this incident caused the EASA (European Aviation Safety Agency) issued as a recommendation to guarantee the presence of two crew members in the cockpit during all the flight, at least one of them should be a pilot [99].

However, this regulatory changes should be accompanied by other additional debate, in order to redefine aircraft passenger cabin and cockpit layout. The aim of this redefinition should be to maximize aircraft security, as well as to provide a superior ergonomics on the passenger seats. This act of improvement should include a rigorous study that considers modifications in the number of seats per row, or the adequate seat pitch and seat width to keep a high ergonomic level.

Additionally, it should be treated the possibility of incorporating an aircraft lavatory just for the cockpit. The implementation of this measure would drastically reduce possibilities to suffer an air accident in the same conditions, since inside the flight desk operational security would be increased and flight crew absence inside the cockpit would also be minimized. Below this paragraph can be observed the aircraft lavatory location on A320 aircraft, as well as the key elements to notify and enable the entry and exit from/to de cockpit.

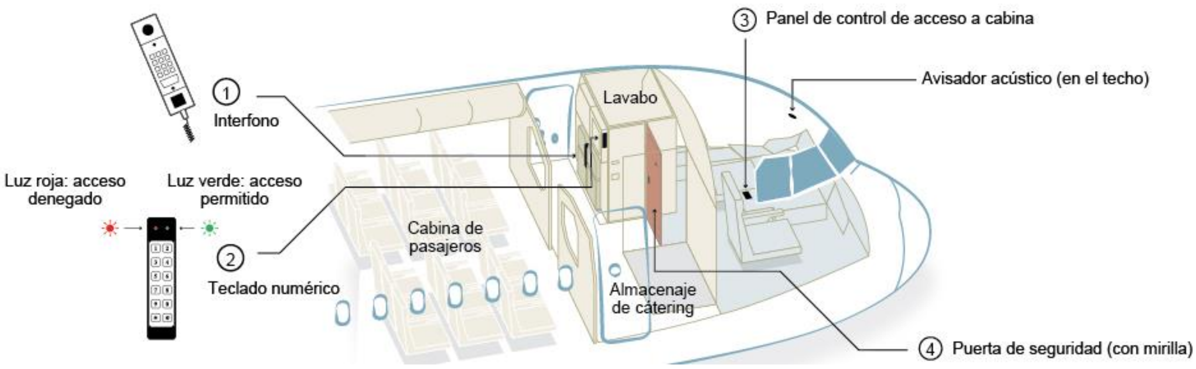

Figure 52. *Aircraft lavatory location on Germanwings A320 Flight 9525 [100].*

CHAPTER 7: CONCLUSIONS

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7.1. Final conclusions

Commercial aviation and its airplane passengers are on the rise since, as mentioned in the introductory chapter, Total Passenger Market, from year 2007 to half of year 2014, had passed from 3.62 bill to 5 bill RPKs [19]. Due to this fact, and whether it is followed a detailed analysis to growth prospects, it can be concluded airplane passengers will spend an increasing amount of time seated on his/her aircraft seat. This increment has motivated the development of this project, which integrates a series of landmarks that have been a reference during the execution of this investigation.

The performance of a complete ergonomic risk assessment has supposed the identification and definition of sixteen working postures and common seated positions, classified in five working groups. Ergonomic risk assessment has mainly been performed by two direct methods of biomechanical analysis: ERGO/IBV-REBA (where the REBA score system and its principles are followed to define the map of main body regions that are exposed to suffer an ergonomic impact) and 3DSSPP (this ergonomic tool has enabled assessment of baby posture, whose complexity while holding a considerable load makes necessary to incorporate is the possibility to input anthropometric data and to rank people in percentiles).

ERGO-IBV ergonomic risk assessment reveals 9 seated postures present a low ergonomic risk level, and none of them are considered as a potential risk of discomfort. However, 7 risk out of 16 has been prioritized as medium risk level, what suppose this positions are in the limit between commodity and ergonomics. This result evidence the necessity of conducting, for these 7 postures, a deeper analysis to determine, with the support of auxiliary tools, whether it is necessary to adopt any type of modification to improve commodity/ergonomics of airplane passengers, when adopted the specific posture.

3DSSPP assessment marks baby posture, which was previously identified as a medium risk level posture, does not suppose an ergonomic risk and the diagnosis is acceptable.

Afterwards, the FMEA has been applied in those postures whose ergonomic risk level, previously assessed with ERGO-IBV method, is sufficiently high to be considered a potential risk for the passenger, in terms of commodity and ergonomics. Priority risk indicates 5 postures out of 7 postures assessed have a low criticality level, whilst 2 postures out of 7 evidence the necessity of implementing changes. The two postures identified with a medium priority risk are sleeping postures, specifically with the torso in a turned position.

The implementation of changes makes necessary a revision of typical cabin configurations, which specially affect to aircraft seat dimensions, what is directly associated with airplane passenger’s commodity and ergonomics.

7.2. Future tendencies

Future of commercial aviation is in a constant redesign phase. In November 2014, Airbus patented a new aircraft model in the United States that supposes a new concept in the air passengers market. The airplane, which has a circular shape, would enable to reduce or to eliminate the necessity of sealing the lower part of the aircraft, what would ostensibly reduce the overall fuel burn, at the same time it would contribute to a greater capacity of transport [101, 102].

This prototype has been designed to transport about a hundred airplane passengers, as can be observed in the next design images:

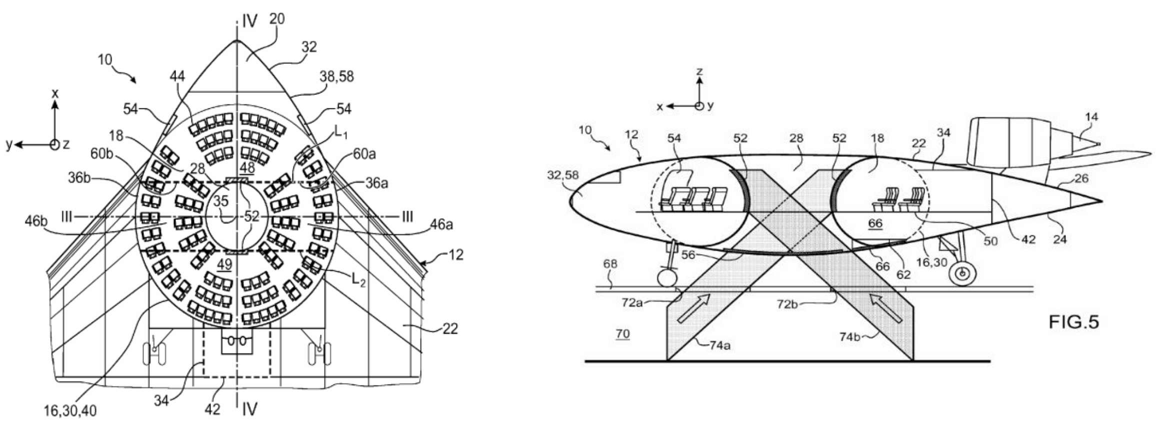

Figure 53. *Upper part and left lateral view of a new Airbus prototype airplane [101].*

Another concept could become a reality during next years is vertical seating. This redefinition of the airplane passenger's way of transportation would enormously reduce operational flight costs, since the number of passengers that can be accommodated in the cabin would be increased. As of today, no vertical plane seat model has been approved to be used in the domain of the commercial aviation [103].

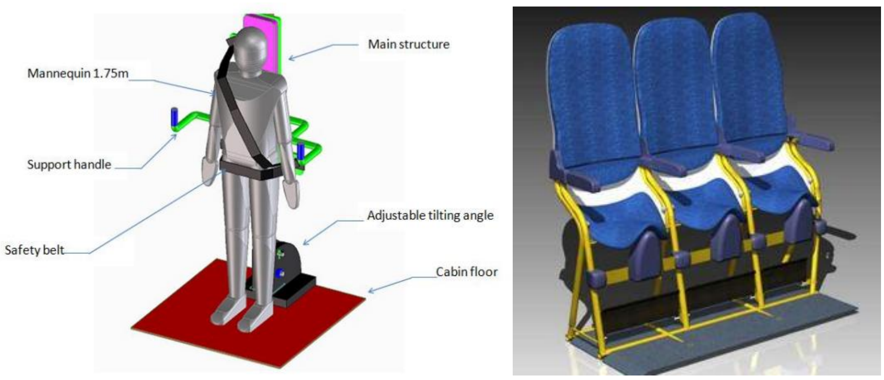

Figure 54. *Design illustration and stand up seat diagram [103].*

CHAPTER 8: BUDGET

The budget of this project has been elaborated under the premise of minimizing the cost and maximizing resource efficiency. In order to achieve this principle, software employed for postural risk assessment has been the free trial version. Despite this fact, in this budget will be considered as it would have been used the full version, since whether this bachelor thesis was a real consulting report, the computer tools available to conduct the project would be totally accessible, not only for a limited period of time.

In this way, the project budget is divided in different concepts, all of them are grouped in the paragraphs below:

- Aircraft seating ergonomic study in commercial aviation and postural definition.

  In this section are grouped all the steps given in order to perform a photography of the current situation in the commercial aviation and main ergonomic problems a standard air passenger may experience while he or she is seated on a plane seat. It will be treated the potential risk of developing a MSD and pain sensation.

  After this exhaustive investigation, under the necessity of a basis of sustenance that permits to achieve a realistic postural risk assessment, it will follows a postural catalogue definition. The set of postures have been selected after effecting a comparative analysis, amongst existing common seated positions in the commercial aviation. This common postures have always been extracted from current seating configurations in the airlines.

- Direct observation methods definition and software purchase.

  This section of the project includes the search and justification of most suitable methods for the ergonomic risk assessment. After this decision, it proceed to obtain ergonomic software tools that will be applied in the ergonomic analysis.

- Postural risk assessment

  In this stage, the evaluator performs a technical analysis, in which different variables are introduced in the computer applications. This parameters, such as body segments angle or the work load the body experiments, enables different ergonomic applications to calculate an ergonomic risk diagnosis.

- Diagnosis and future/possible solutions

  The final procedure consist on a final analytical revision of existing situation with obtained results and the establishment of possible solutions and future tendencies.

Description	Quantity	Unitary Price	Price
Aircraft seating ergonomic study in commercial aviation and postural definition. *It includes:*			7.000€
- Current situation in commercial aviation study	1 unit	1.500 €/unit	
- Ergonomic study that introduces and consider the sensation of pain definition an potential MSDs susceptible to appear while developing a seated position in a flight	1 unit	2.500 €/unit	
- Postural catalogue definition	1 unit	3.000 €/unit	
Direct observation methods definition and software purchase. *It includes:*			3.700 €
- Direct observation methods / Direct methods of biomechanical analysis selection for ergonomic assessment	1 unit	1.500 €/unit	
- Ergo/IBV V14 software acquisition	1 unit	800€/unit	
- 3DSSPP Version 6 software acquisition	1 unit	1.400 €/unit	
- FMEA worksheet acquisition	1 unit	0 €/unit (own resources)	
Postural risk assessment. *It includes:*			
- Technical analysis of postural catalogue with selected ergonomic tools.	1 unit	7.500 €/unit	7.500 €
Diagnosis and future/possible solutions. *It includes:*			4.000 €
- Ergonomic recommendations, according to final results	1 unit	2.500 €/unit	
- Future tendencies in aircraft seating sector	1 unit	1.500 €/unit	

TOTAL COST: 22.200 €

Table 15. *Breakdown of consulting services budget.*

The implementation of the budget is linked to the development of operations have been performed during the execution of the present bachelor thesis. In the chart below, it can be observed a detailed project planning that contains the sequence of work steps that have succeeded from the initial conception of the project, to the completion of the study:

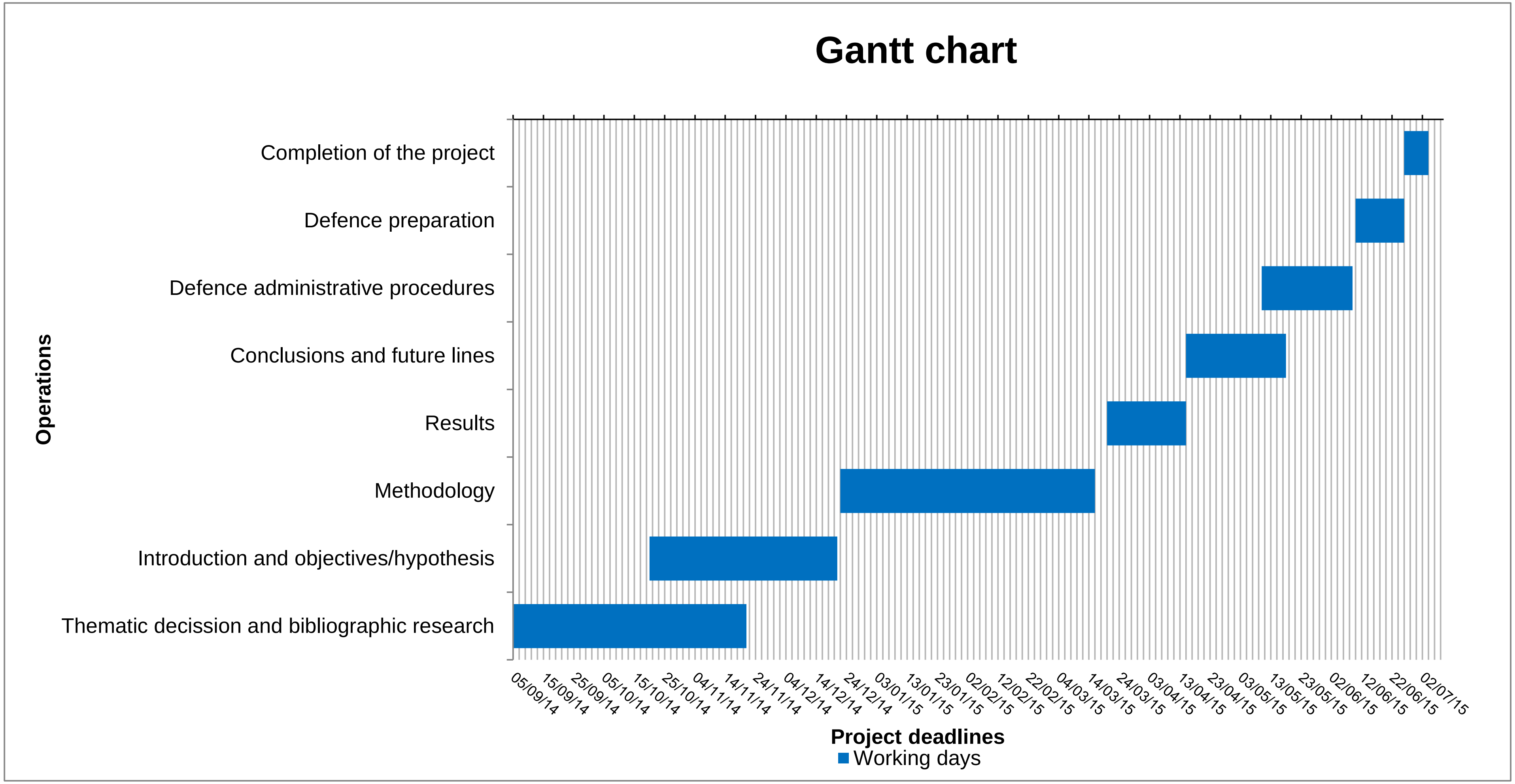

Table 16. *Project planning.*

CHAPTER 9: REFERENCES

Universidad Carlos III de Madrid

[1] The Guardian. (2011, 28 February 2015). *Infant ticket prices on some airlines have increased 33% since last year.* Available: http://www.theguardian.com/money/2011/jun/16/warning-infant-fares-airlines

[2] CNN Mexico. (2013, 28 February 2015). *Las 20 cosas más molestas que los pasajeros hacen en los aviones*. Available: http://mexico.cnn.com/salud/2013/12/06/las-20-cosas-mas-molestas-que-los-pasajeros-hacen-en-los-aviones

[3] C. F. Tan, W. Chen, F. Kimman, and G. W. M. Rauterberg, "Sleeping Posture Analysis of Economy Class Aircraft Seat," presented at the World Congress on Engineering, London (UK), 2009.

[4] IEA. (2014, 29 December 2014). *Definition and Domains of ergonomics*. Available: http://www.iea.cc/whats/index.html

[5] Institute of Ergonomics and Human Factors. (2014, September 5). *What is ergonomics?* Available: http://www.ergonomics.org.uk/learning/what-ergonomics

[6] C. Gungor, "A Human Factors and Ergonomics Awareness Survey of Professional Personnel in the American Furniture Industry," Forest Products, Mississipi State University, Ann Arbor, United States, 2009.

[7] S. Rozlina, M. Shaharoun Awaluddin, S. H. Syed Abdul Hamid, and Z. Norhayati, "Perceptions of Ergonomics Importance at Workplace and Safety Culture amongst Safety & Health (SH) Practitioners in Malaysia," presented at the Proceedings of the World Congress on Engineering, London, U.K., 2012.

[8] A. L. Abrams. (2001-2002, Safety Management Programs Make Dollars and Sense. *(II)*. Available: http://www.asse.org/professionalaffairs_new/positions/roi.php

[9] European Comission, "EU Transport in Figures," Statistical Pocketbook 978-92-79-21694-7, 2012.

[10] UNECE, "The UNECE Transport Statistics for Europe and North America," vol. 56, E. C. f. Europe, Ed., ed. Geneva, 2011.

[11] Eurostat, "Energy Consumption and dependence rates 2008-2011," 2013.

[12] Glassbrenner D., "An Analysis of Recent Improvements to Vehicle Safety," ed: U.S. Department of Transportation, 2012, p. 85.

[13] Falck A., "Ergonomics Methods and Work Procedures in Car Manufacturing for Improvement of Quality, Productivity and Health at Work," Chalmers University of Technology, 2009.

[14] Dirección General de Tráfico, "Balance de Seguridad Vial 2013," O. d. C. y. R. Institucionales, Ed., ed, 2013, p. 6.

[15] Ergotron, "Uso de un ordenador portátil con comodidad: la ecuación ergonómica " 2008.

Universidad Carlos III de Madrid

[16] Health and Safety Executive. (2014, 7 September 2014). *Muskuloskeletal Disorders (MSDs)*. Available: http://www.hse.gov.uk/msd/

[17] Civil Aviation Authority (CAA), "Summary of the meaning of Commercial Air Transport, Public Transport & Aerial Work," 2010.

[18] F. Pharand-Deschenes, "Satellite images of Earth show roads, air traffic, cities at night and internet cables," in *The Telegraph*, ed, 2014.

[19] International Air Transport Association (IATA), "Air Passenger Market Analysis," 2014.

[20] Massachusetts Institute of Technology. (2014, 9 September 2014). *Airline Data Project: Glossary. Massachusetts Institute of Technology Global Airline Industry Program*. Available: http://web.mit.edu/airlinedata/www/default.html

[21] G. Brundrett, "Comfort and health in commercial aircraft: a literature review," *The Journal of the Royal Society for the Promotion of Health,* vol. 121 (1), pp. 29-37, 2001.

[22] C. F. Tan, "Smart system for aircraft passenger neck support," Technische Universiteit Eindhoven, Eindhoven, 2010.

[23] Vink P. and Brauer K., *Aircraft interior comfort and design*. United States of America, 2011.

[24] World Health Organization, *International travel and health*. Switchzerland, 2005.

[25] Coleman R. and Kim I., "Dealing with Jet Lag," *Chemical Engineering,* vol. 105, p. 125, 1998.

[26] British Airways. (2014, 15 November 2014). *Jet lag advisor*. Available: http://www.britishairways.com/travel/drsleep/public/en_gb

[27] Goosens R., Teeuw R., and Snijders C., "Sensitivity for pressure difference on the ischial tuberosity," *The Official Journal of the Chartererd Institute for Ergonomics and Human Factors,* vol. 48, 2005.

[28] Goosens R., "Measuring factors of discomfort in office chairs. In Global Economics," presented at the Procedings of the economic Conference, Amsterdam, 1998.

[29] Looze M. P., Kuijt- Evers L., and Van Dieën J. H., "Sitting comfort and discomfort and the relationship with objective measures," *The Official Journal of the Chartererd Institute for Ergonomics and Human Factors,* vol. 46, pp. 985-997, 2003.

[30] XSensor Technology Corporation. (2014, 15 November 2014). *XSENSOR Pressure Imaging Systems*. Available: http://www.xsensor.com/Test-and-Measurement-Solutions

[31] Qatar Airways. (2014, 24 December 2014). *In-flight exercises*. Available: http://www.qatarairways.com/us/en/fly-healthy-fly-fit.page

[32] H. Hamberg-van Reenen, "Physical capacity and work related muskuloskeletal symptons," Vrije Universiteit, Amsterdam, 2008.

[33] A. Parent-Thirion, H. F. Macías, J. Hurley, and G. Vermeylen, "Fourth European Working Conditions Survey," The European Foundation for the Improvement of Living and Working Conditions, Dublin2007.

[34] Apex, "The new seats are slimmer so they are being fitted closer together," ed: Daily Mail, 2013.

[35] S. Hernández Cueto, *Valoración médica del daño corporal* vol. 2. Barcelona: Elsevier, 2001.

[36] V. Zorrilla Muñoz, "Trastornos musculoesqueléticos de origen laboral en el sector de la construcción," Departamento de Ingeniería Mecánica, de Energía y de los Materiales, Universidad de Extremadura, 2012.

[37] University of Calgary. (2014, 22 September 2014). *The Psychology Instruction Project. Mod7. Why is Pain Important?* Available: http://ucalgary.ca/pip369/mod7/tempain/impo

[38] Cleveland Clinic. (2008, 28 September 2014). *Acute vs. Chronic Pain*. Available: http://my.clevelandclinic.org/services/anesthesiology/pain-management/diseases-conditions/hic-acute-vs-chronic-pain

[39] European Agency for Health and Safety at Work. (2007, Work-related musculoskeletal disorders (MSDs): an introduction Available: https://osha.europa.eu/en/publications/e-facts/efact09

[40] Canadian Centre for Occupational Health and Safety. (2014, 27 September 2014). *Work-related Muskuloskeletal Disorders (WMSDs)*. Available: http://www.ccohs.ca/oshanswers/diseases/rmirsi.html

[41] Occupational Safety and Health Administration (OSHA). (2015, 11 January 2015). *Good Working Positions*. Available: http://www.osha.gov/SLTC/etools/computerworkstations/positions.html

[42] Engström B, *Ergonomic Seating. A True Challenge. Wheelchair Seating and Mobility Principles* Sweden, 2002.

[43] Neville L., "The Fundamental Principles of Seating and Positioning in Children and Young People with Physical Disabilities," BSc Occupational Therapy, University of Ulster, 2005.

[44] E. M. Green and R. L. Nelham, "Development of sitting ability, assessment of children with a neuromotor handicap and prescription of appropriate seating systems " presented at the Prosthetics and Orthotics International, Lewes (UK), 1991.

[45] Lange M.L., "Focus on….Positioning philosophies," *Occupational Therapy Practice* pp. 15-16, 2001.

[46] Jones M and Gray S, "Assistive technology: positioning and mobility," in *Meeting the Physical Therapy Needs of Children*, S. Effgen, Ed., ed, 2005.

[47] Trueman M., "Are you sitting comfortably in the theatre?," ed: The Guardian, 2011.

[48] Howe T and Oldham J, "Posture and balance," in *Human Movement: An Introductory Text*, In M Trew and Everett T, Ed., ed London: Churchill Livingston Elsevier, 2001.

[49] Samson, *Healthy Computing: Stay Healthy and Avoid Injury While Working Long Hours on your PC*: CreateSpace Independent Publishing Platform, 2010.

[50] American Ergonomics Corporation. (2006, 11 January 2015). *CBM Dynamic Seat for Aircraft Main Cabin*. Available: http://americanergonomics.com/?page=air-designs

[51] Catay Pacific. (2012, 17 January 2015). *Cathay Pacific takes delivery of first aircraft with new Premium Economy product and long-haul Economy Class seats*. Available: http://www.cathaypacific.com/content/dam/cx/digital-library/hk/press-release/archived/pack01/20120227_2.jpg

[52] CNA Financial Corporation, "Risk Control Bulletin: Maximizing Comfort While Using Your Laptop," 2010.

[53] Lucas Jackson. (2014, 22 February 2015). *Airlines Expand In-Flight TV and Movies to Connected Travelers*. Available: http://www.nbcnews.com/business/travel/airlines-expand-flight-tv-movies-connected-travelers-n103356

[54] Alamy. (2013, 22 February 2015). *U.S. to lift 'outdated' ban on airline passengers using laptops during takeoff and landing*. Available: http://www.dailymail.co.uk/news/article-2346169/U-S-lift-outdated-ban-airline-passengers-using-laptops-takeoff-landing.html

[55] Linkedin. (2014, 30 May 2015). *Direct Air-to-Ground Communications DA2GC: WiFi on aircrafts in Europe*. Available: http://www.linkedin.com/pulse/direct-air-to-ground-da2gc-wifi-umberto

[56] Joseph E. Muscolino, "Reading, Writing & Posture," Massage therapy journal2012.

[57] British Airways. (2015, 22 February 2015). *Seat type and price guide*. Available: http://www.britishairways.com/en-gb/information/seating/choosing-your-seat

[58] Huffington Post. (2014, 22 February 2015). *7 Shameless Ways To Get An Upgrade*. Available: http://www.huffingtonpost.com/smartertravel/seven-shameless-ways-to-g_b_5906310.html

[59] Air New Zealand. (2010, 28 February 2015). *Economy Skycouch*. Available: http://www.airnewzealand.com/economy-skycouch

[60] Daily Mail. (2010, 28 February 2015). *Air New Zealand's Skycouch too pricey? Economy class flights can still be sweet dreams*. Available: http://www.dailymail.co.uk/travel/article-1250933/Air-New-Zealands-Skycouch-pricey-Economy-class-flights-sweet-dreams.html

[61] Rauterberg M., "Userfit Tools: Direct Observation," Technische Universteit Eindhoven, Nederlands2014.

[62] Leading Edge Physical Therapy. (2014, 1 November 2014). *Biomechanical Analysis*. Available: http://leadingedgephysicaltherapy.com.au/services/biomechanical-analysis/

[63] Instituto Nacional de Seguridad e Higiene en el Trabajo (INSHT). (2014, 3 November 2014). *Transtornos musculoesqueléticos más frecuentes*. Available: http://www.insht.es/portal/site/MusculoEsqueleticos/

[64] Iowa State University. (2014, 3 November 2014). *Static Postures, Environmental Health and Safety*. Available: http://www.ehs.iastate.edu/occupational/ergonomics/static-postures

[65] American Ergonomics Corporation. (2006, 24 December 2014). *CBM Seat for Aircraft*. Available: http://americanergonomics.com/?page=air

[66] Thomson Reuters, "Airline squeeze – graphic of the day," ed, 2013.

[67] Lynn McAtamney and Nigel Corlett, "RULA: a survey method for the investigation of world-related upper limb disorders " *Applied Ergonomics,* vol. 24 (2), pp. 91-99, 1993.

[68] M. Middlesworth, "A Step-by-Step Guide - Rapid Upper Limb Assessment (RULA)," 2012.

[69] Cornell University. (2001, 24 December 2014). *RULA Worksheet*. Available: http://ergo.human.cornell.edu/ahrula.html

[70] NexGen Ergonomics. (2014, 5 November 2014). *ErgoIntelligence Upper Extremity Assessment* Available: http://www.nexgenergo.com/ergonomics/ergointeluea.html

[71] M. Middlesworth, "A Step-by-Step Guide: Rapid Entire Body Assessment (REBA)," 2012.

[72] Sue Highnett and Lynn McAtamney, "Rapid Entire Body Assessment (REBA)," *Applied Ergonomics,* vol. 31 (2), pp. 201-205, 2000.

[73] University of South Florida. (2004, 24 December 2014). *REBA Employee Assessment Worksheet*. Available: http://personal.health.usf.edu/tbernard/HollowHills/REBA.pdf

[74] Nogareda S., "NTP 601: Evaluación de las condiciones de trabajo: carga postural. Método REBA (Rapid Entire Body Assessment) " Instituto Nacional de Seguridad e Higiene en el Trabajo (INSHT)2001.

[75] Kee D. and Karwowski W., "LUBA: an assessment technique for postural loading on the upper body based on joint motion discomfort and maximum holding time," *Applied Ergonomics,* vol. 32, pp. 357-366, 2001.

[76] Nogareda S., "NTP 674: Evaluación de la carga postural: método de la Universidad de Lovaina, método LUBA " Instituto Nacional de Seguridad e Higiene en el Trabajo (INSHT)2004.

[77] Andreoni G., Mazzola M., Ciani O., Zambetti M., Romero M., Costa F., *et al.*, "Method for Movement and Gesture Assessment (MMGA) in Ergonomics," in *Digital Human Modeling*, ed: Springer Berlin Heidelberg, 2009, pp. 591-598.

[78] Nogareda S. and Álvarez A., "NTP 622. Carga postural. Técnica goniométrica. Notas Técnicas de Prevención.," Instituto Nacional de Seguridad e Higiene en el Trabajo (INSHT)2001.

[79] Biomechanics Institute of Valencia. (2011, 15 February 2015). *Ergo/IBV Evaluación de riesgos ergonómicos*. Available: http://www.ibv.org/es/productos/aplicaciones-ibv/show_product/82/292

[80] National Institute for Occupational Safety and Health - North Carolina State University, "Advancing the Science of Ergonomics in the Workplace," NC State University2011.

[81] University of Michigan. (2014, 5 November 2014). *3D SSPP*. Available: http://umich.edu/~ioe/3DSSPP/

[82] Technische Universität München. (2015, 25 January 2015). *RAMSIS — 3D human model for CAD applications*. Available: http://www.lfe.mw.tum.de/en/research/methods-and-lab-equipment/ramsis-3d-human-model-for-cad-applications/

[83] Human Solutions GmbH. (2015, 25 January 2015). *Ergonomics for Digital Product Development*. Available: http://www.tecmes.com.br/wp-content/uploads/2014/02/RAMSIS_Aircraft_Flyer_en.pdf

[84] FBF Sistemas. (2009, 5 November 2014). *ErgoFellow*. Available: http://www.fbfsistemas.com/ergonomics.html

[85] Smith K. and Walker B. (2004, Integrating ergonomics. *InTech 51,* 38-41. Available: http://search.proquest.com/docview/208808391?accountid=14501

[86] Everett J., "Ergonomic analysis of construction tasks for risk factors for overexertion injuries.," Ann Arbor: Department of Civil & Environmental Engineering, University of Michigan1997.

[87] McCauley P., Gaines S., Gammoh F., and Wooden S., "A Comparison of Software Tools for Occupational Biomechanics and Ergonomic Research," D. I. L. Nunes, Ed., ed University of Central Florida, Orlando, Florida, USA: http://www.intechopen.com, 2012, p. 71.

[88] Bestratén M. and Orriols R., "NTP 679. Failure Mode and Effect Analysis. FMEA," Instituto Nacional de la Seguridad e Higiene en el Trabajo2004.

[89] Schnauber G., "FMEA Ranking Criteria," 2011.

[90] Shafiee M. and Dinmohammadi F. (2014, An FMEA-Based Risk Assessment Approach for Wind Turbine Systems: A Comparative Study of Onshore and Offshore. *Energies,* 619-642. Available:

http://web.b.ebscohost.com.strauss.uc3m.es:8080/ehost/pdfviewer/pdfviewer?sid=69ff9dae-daee-45fb-a2e8-8ab5eba973ef%40sessionmgr114&vid=1&hid=106

[91] Sellappan N. and Palanikumar K. (2013, Modified Prioritization Methodology for Risk Priority Number in Failure Mode and Effects Analysis. *International Journal of Applied Science and Technology Vol. 3,* 27-36. Available: http://www.ijastnet.com/journals/Vol_3_No_4_April_2013/3.pdf

[92] Ryanair. (2015, 10 May 2015). *Aircraft seat dimensions*. Available: http://www.ryanair.com/en/questions/aircraft-seat-dimensions/

[93] Wagner P., "Condiciones ergonómicas durante el trayecto en avión en clase turista," MSc en Prevención de Riesgos Laborales, Universidad Politécnica de Valencia, 2011.

[94] Airbus A320. (2015, 19 May 2015). *Dimensions and key data*. Available: http://www.airbus.com/aircraftfamilies/passengeraircraft/a320family/a320/specifications/

[95] Airbus A350 XWB. (2015, 19 May 2015). *Dimensions and key data*. Available: http://www.airbus.com/aircraftfamilies/passengeraircraft/a350xwbfamily/a350-900/specifications/

[96] Civil Aviation Authority. (2003, 20 May 2015). *Seat pitch*. Available: https://www.caa.co.uk/default.aspx?catid=923&pagetype=70&gid=2283&faqid=903

[97] Tovar C., "The Incredible Shrinking Plane Seat," in *The Wall Street Journal*, ed, 2013.

[98] The New York Times. (2015, 25 May 2015). *What Happened on the Germanwings Flight*. Available: http://www.nytimes.com/interactive/2015/03/24/world/europe/germanwings-plane-crash-map.html?_r=0

[99] Bloomberg. (2015, 25 May 2015). *There Weren't Rules to Stop the Germanwings Co-Pilot From Flying Alone*. Available: http://www.bloomberg.com/news/articles/2015-03-26/there-weren-t-rules-to-stop-the-germanwings-co-pilot-from-flying-alone

[100] El País. (2015, 25 May 2015). *Detalles del siniestro del Airbus A320*. Available: http://elpais.com/elpais/2015/03/24/media/1427195967_070152.html

[101] Airbus Operations, "Aircraft including a passenger cabin extending around a space defined outside the cabin and inside the aircraft," USA Patent, 2014.

[102] Financial Times. (2014, 14 June 2015). *Airbus patents flying doughnuts*. Available: http://www.ft.com/cms/s/0/ba80c518-6492-11e4-b219-00144feabdc0.html#slide0

[103] Redzman A. and Fairuz I., "Conceptual Design of Vertical Passenger Seat for Standing Cabin in Commercial Transport Aircraft," *Journal of Advanced Management Science,* vol. 1, pp. 344-348, 2013.

APPENDIX: ERGO/IBV ERGONOMIC RISK ASSESSMENT SCREEN SHOTS

<u>Note:</u> when the tab that includes arms, forearms and wrist body segments angle definition only includes right or left body side is due to the fact that the seated posture is symmetric.

(a) Upright sitting posture

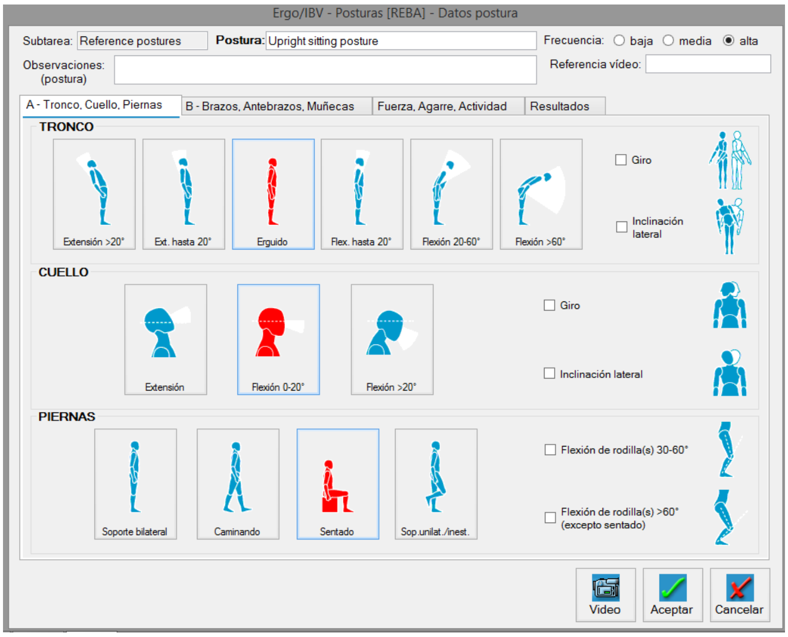

Figure 55. *Screen shot of trunk, neck and legs body segment angle definition in Upright sitting posture.*

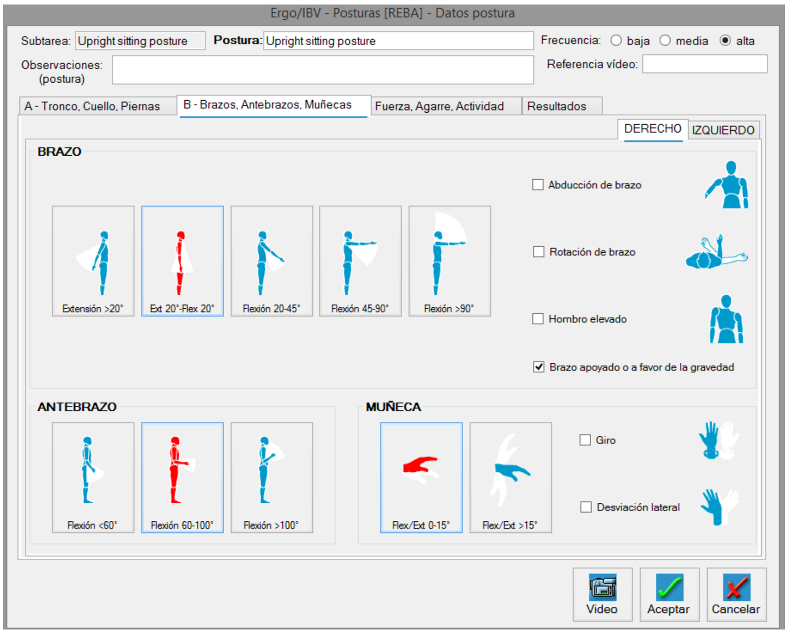

Figure 56. *Screen shot of right/left arm, forearm and wrist body segment angle definition in Upright sitting posture.*

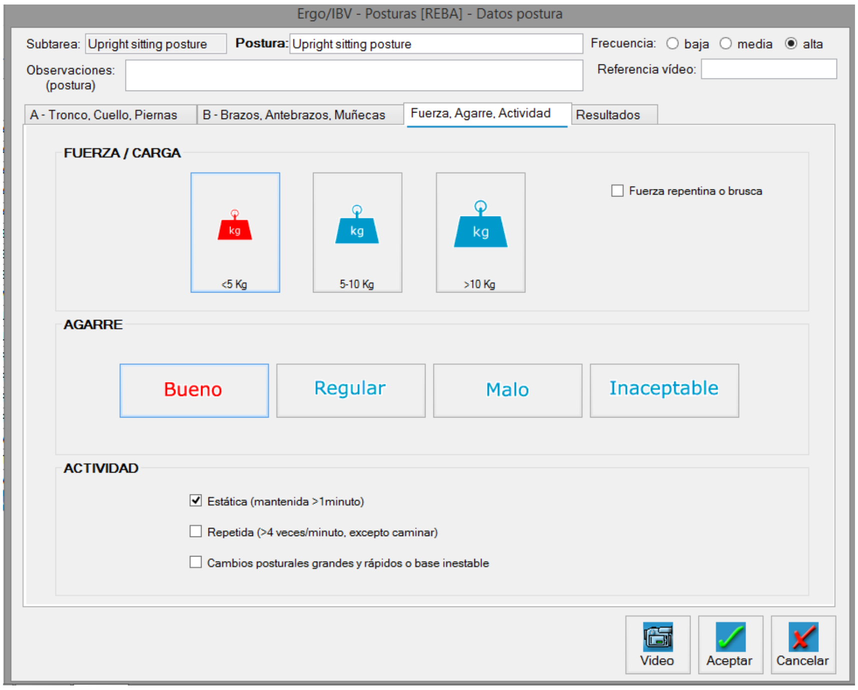

Figure 57. *Screen shot of load, type of grip and activity definition in Upright sitting posture.*

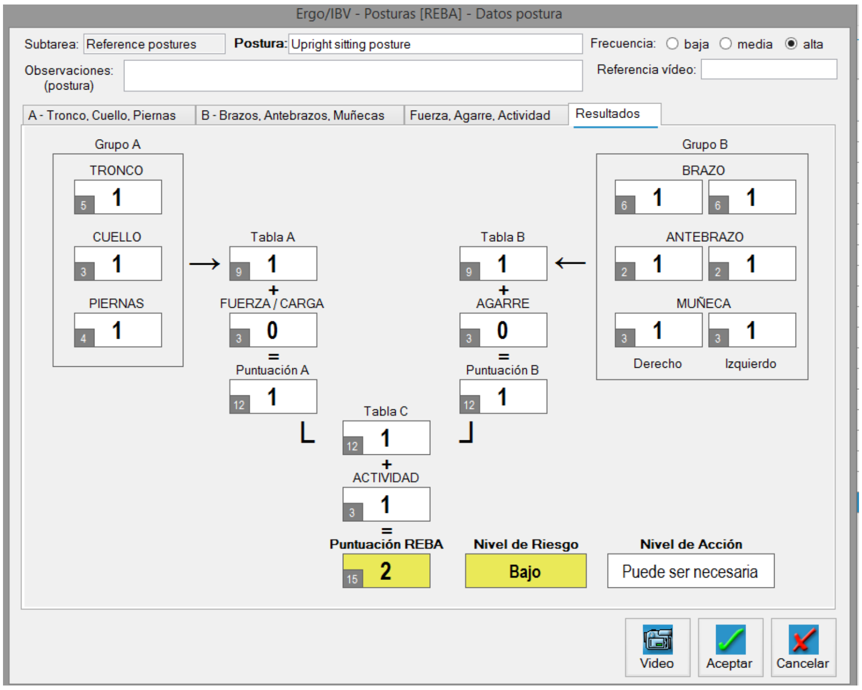

Figure 58. *Screen shot of ERGO/IBV REBA scores in Upright sitting posture.*

(b) Declined sitting posture

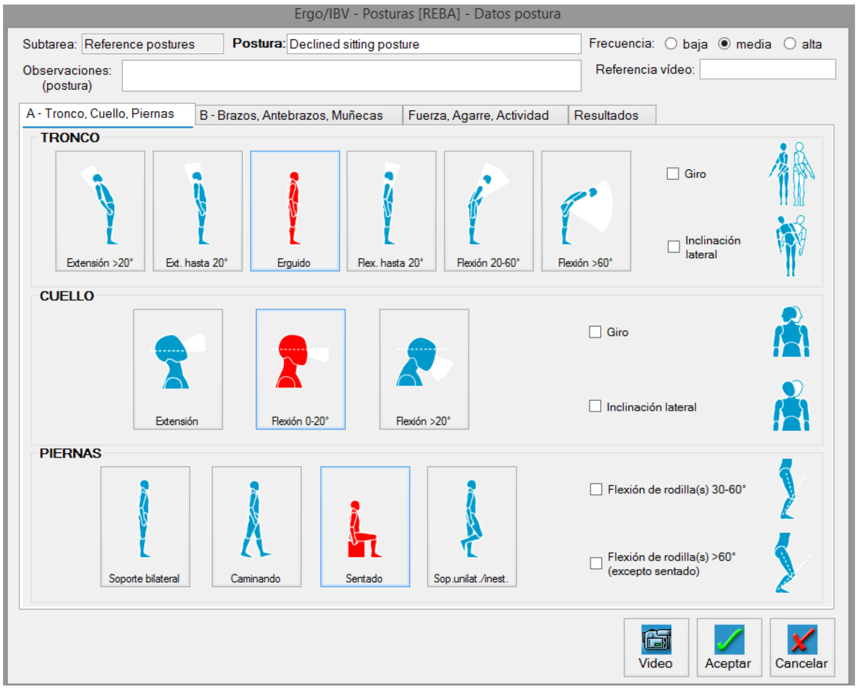

Figure 59. *Screen shot of trunk, neck and legs body segment angle definition in Declined sitting posture.*

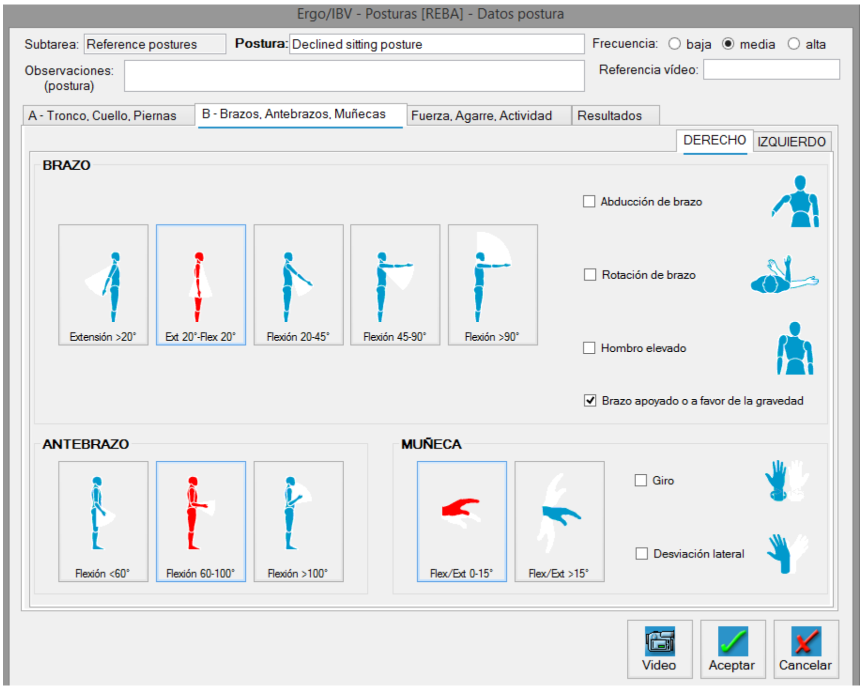

Figure 60. *Screen shot of right/left arm, forearm and wrist body segment angle definition in Declined sitting posture.*

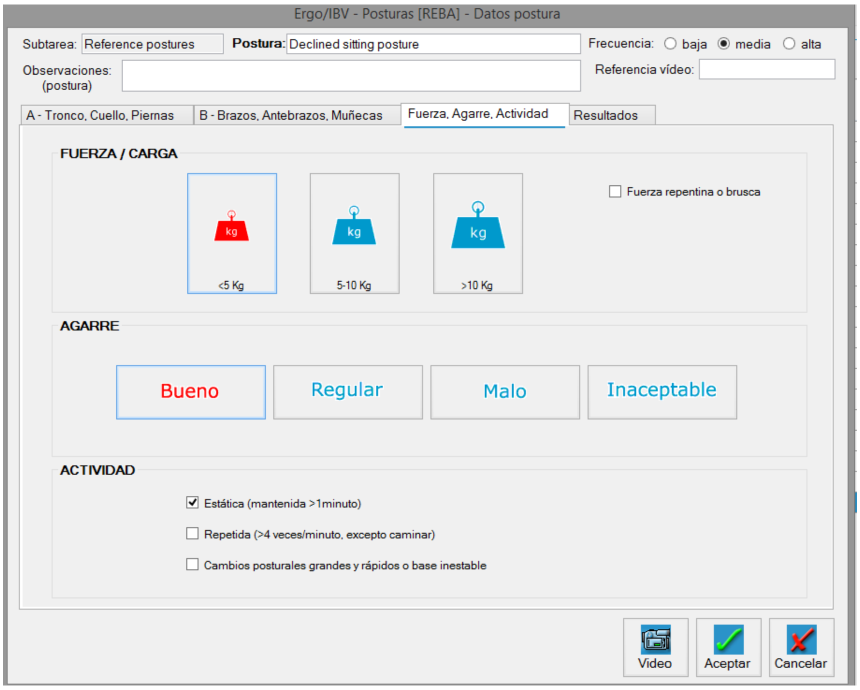

Figure 61. *Screen shot of load, type of grip and activity definition in Declined sitting posture.*

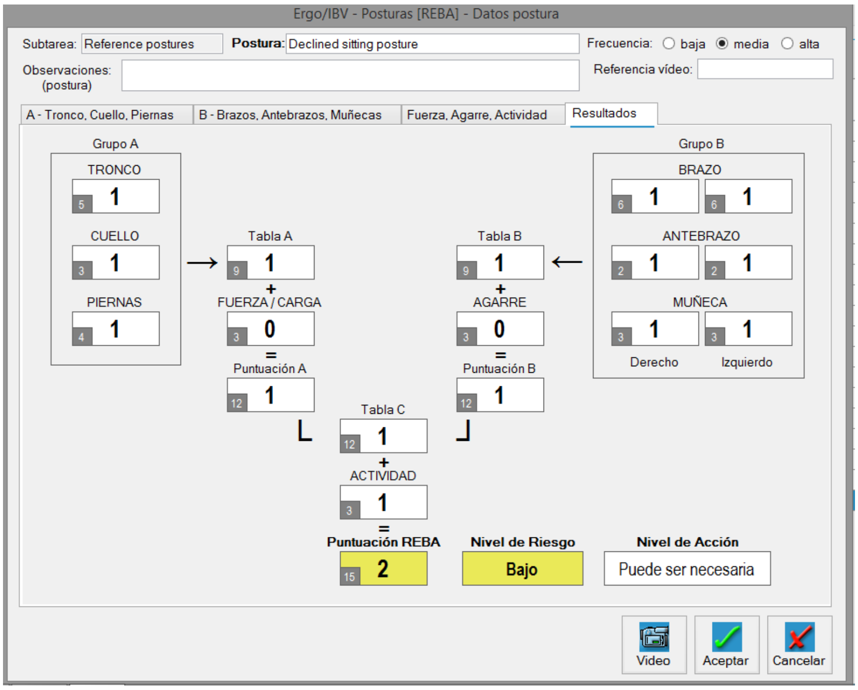

Figure 62. *Screen shot of ERGO/IBV REBA scores in Declined sitting posture.*

(c) Reclined sitting posture

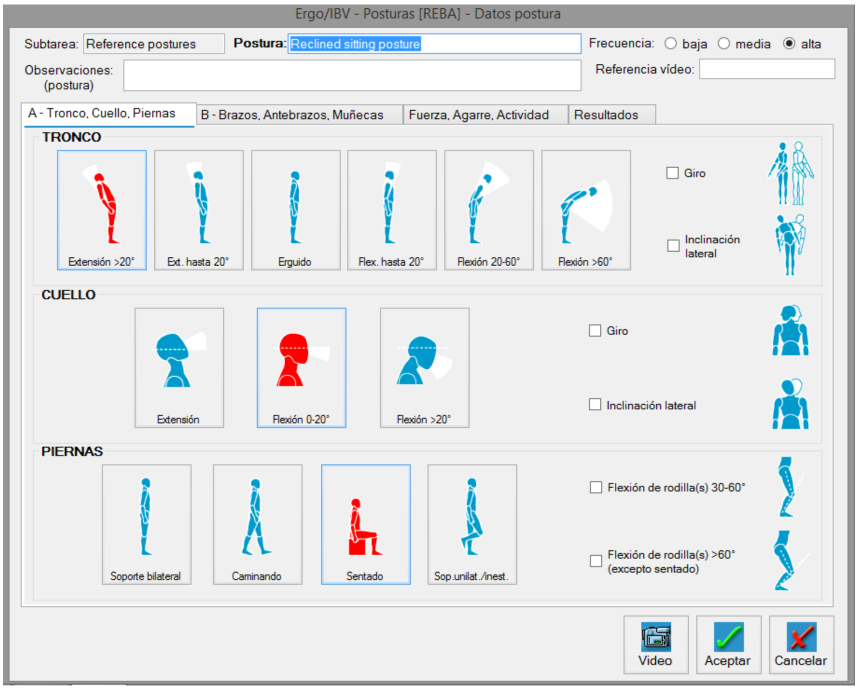

Figure 63. *Screen shot of trunk, neck and legs body segment angle definition in Reclined sitting posture.*

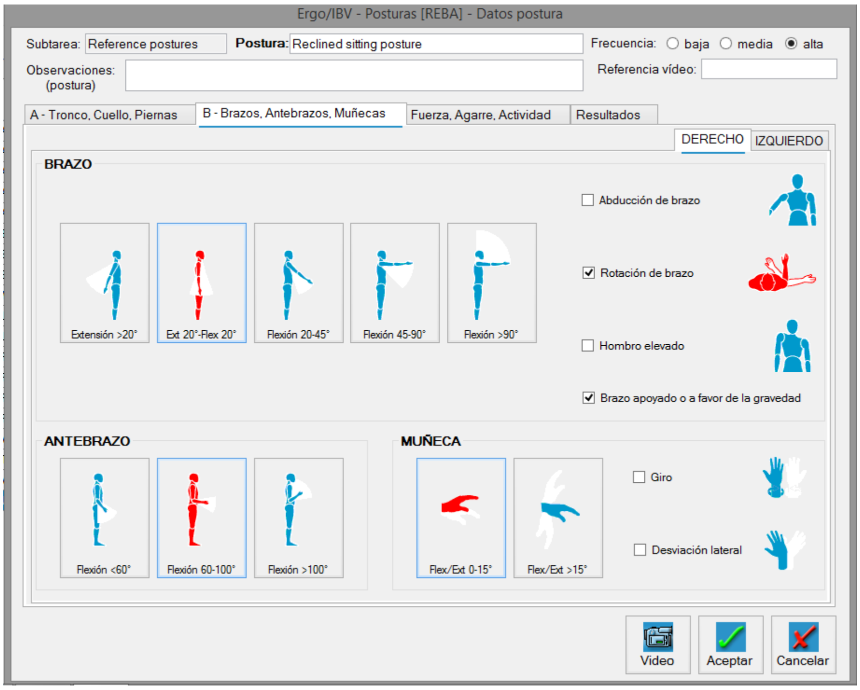

Figure 64. *Screen shot of right/left arm, forearm and wrist body segment angle definition in Reclined sitting posture.*

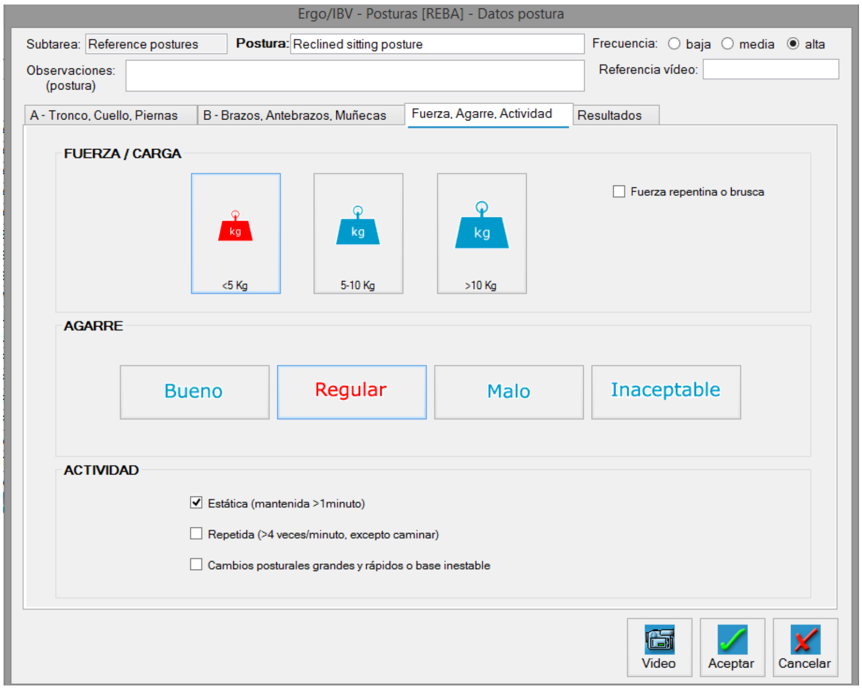

Figure 65. *Screen shot of load, type of grip and activity definition in Reclined sitting posture.*

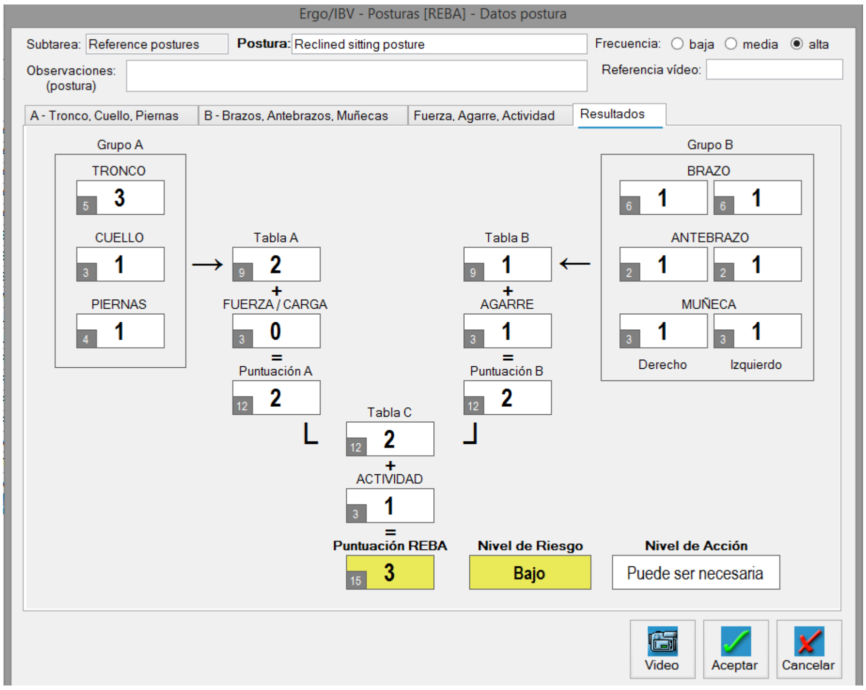

Figure 66. *Screen shot of ERGO/IBV REBA scores in Reclined sitting posture.*

(d) Laptop posture (laptop positioned on a surface in front of the passenger)

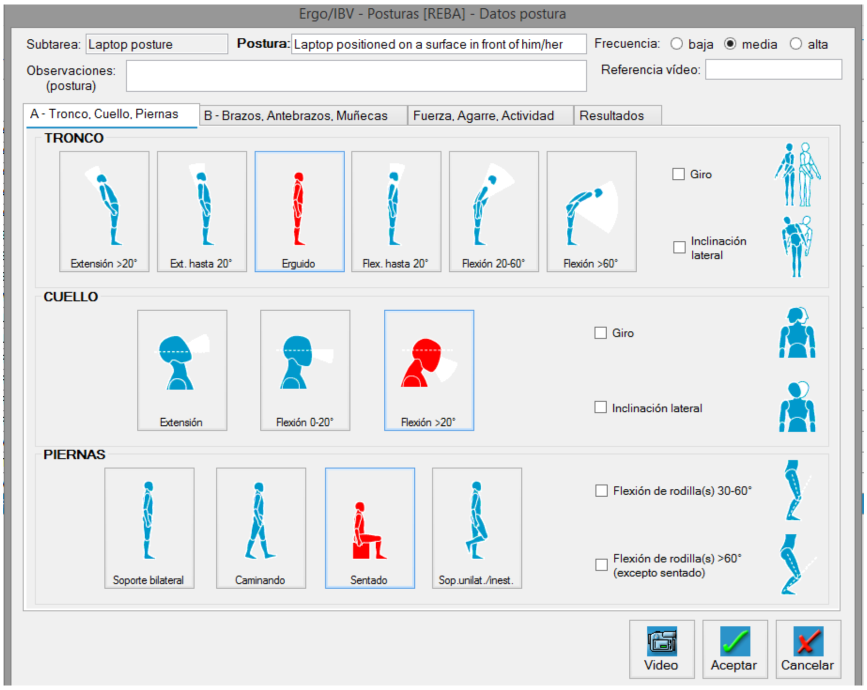

Figure 67. *Screen shot of trunk, neck and legs body segment angle definition in Laptop posture (laptop positioned on a surface in front of the passenger).*

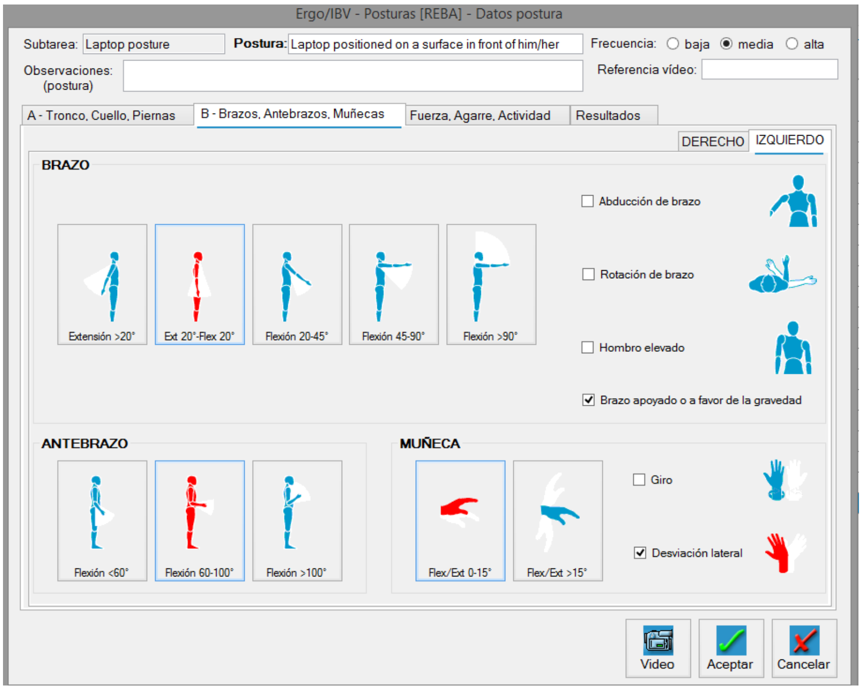

Figure 68. *Screen shot of right/left arm, forearm and wrist body segment angle definition in Laptop posture (laptop positioned on a surface in front of the passenger).*

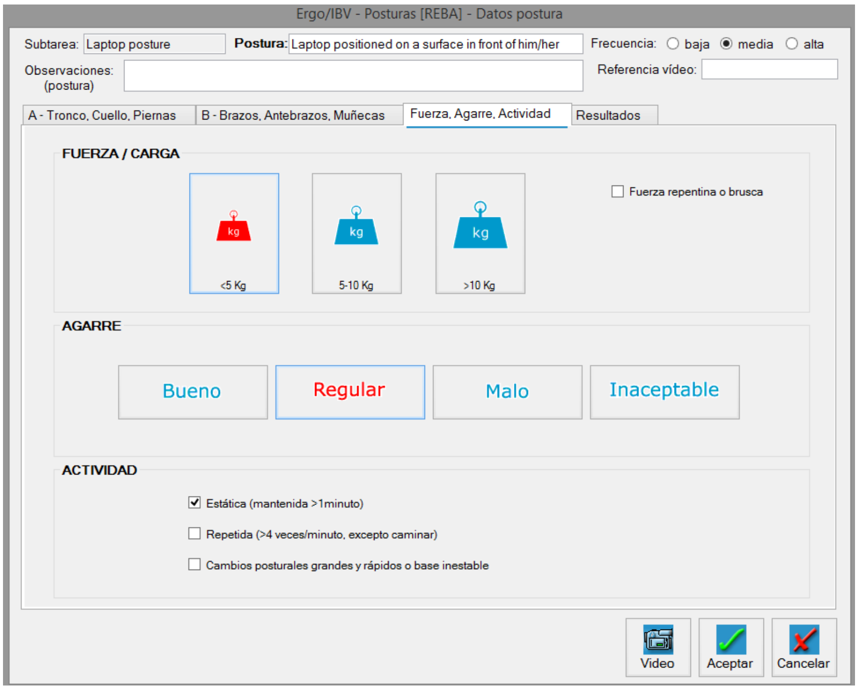

Figure 69. *Screen shot of load, type of grip and activity definition in Laptop posture (laptop positioned on a surface in front of the passenger).*

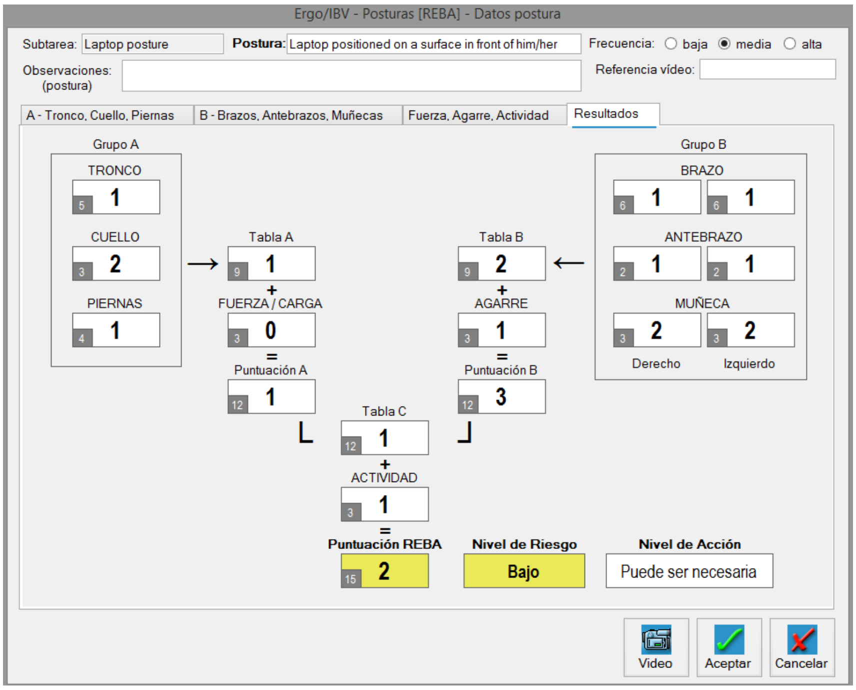

Figure 70. *Screen shot of ERGO/IBV REBA scores in Laptop posture (laptop positioned on a surface in front of the passenger).*

(e) Laptop posture (laptop leant on the passenger's legs)

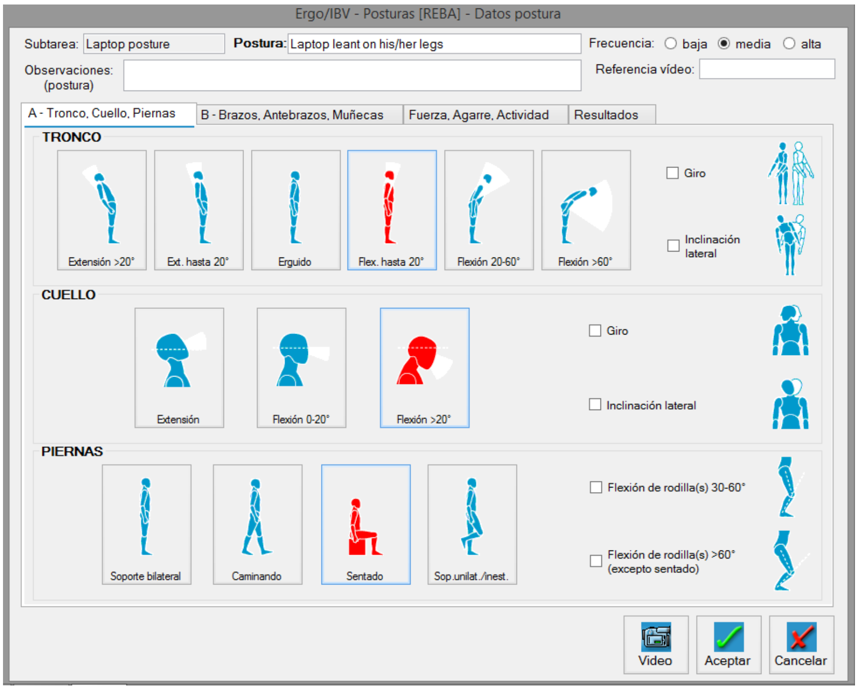

Figure 71. *Screen shot of trunk, neck and legs body segment angle definition in Laptop posture (laptop leant on the passenger's legs).*

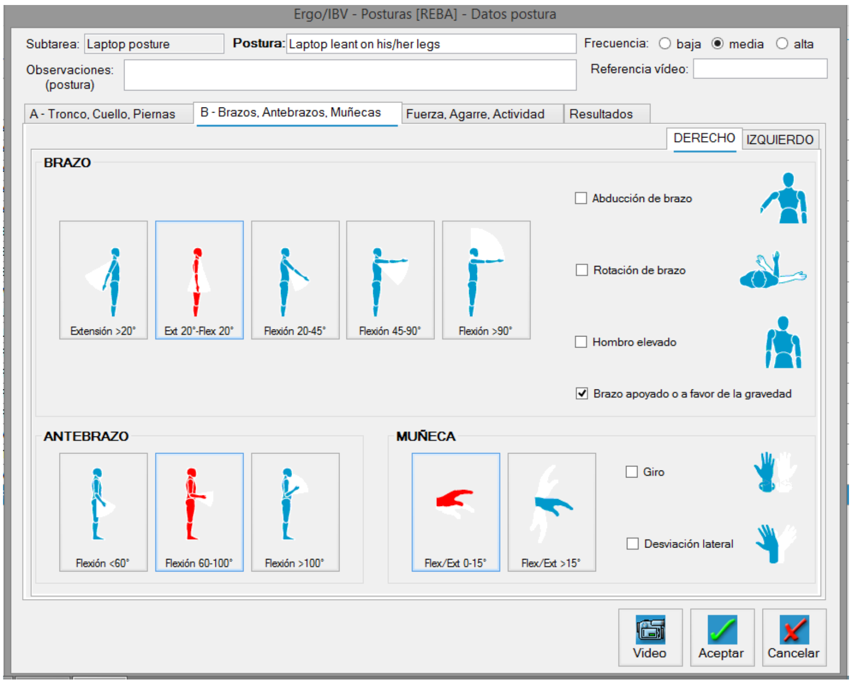

Figure 72. *Screen shot of right/left arm, forearm and wrist body segment angle definition in Laptop posture (laptop leant on the passenger's legs).*

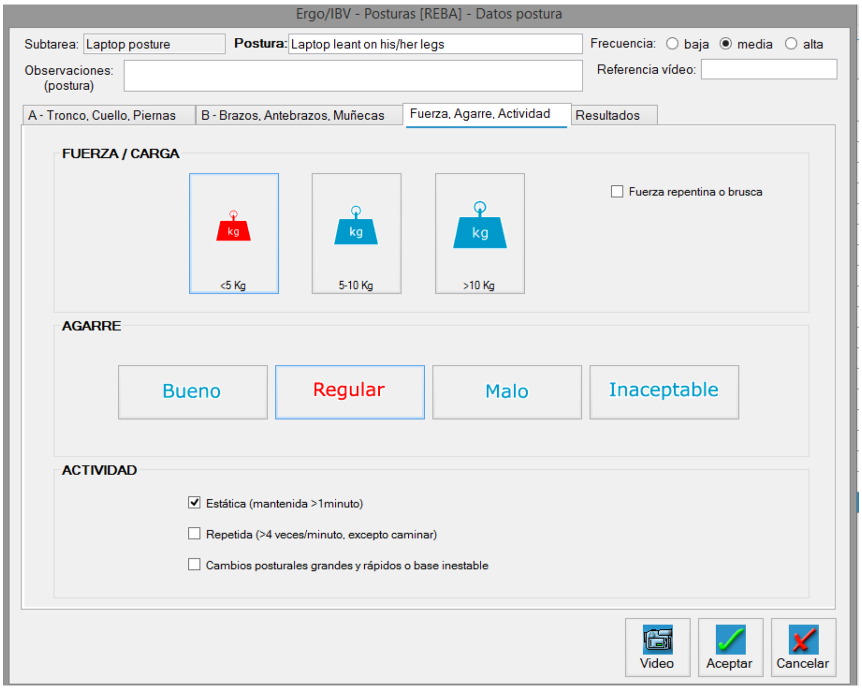

Figure 73. *Screen shot of load, type of grip and activity definition in Laptop posture (laptop leant on the passenger's legs).*

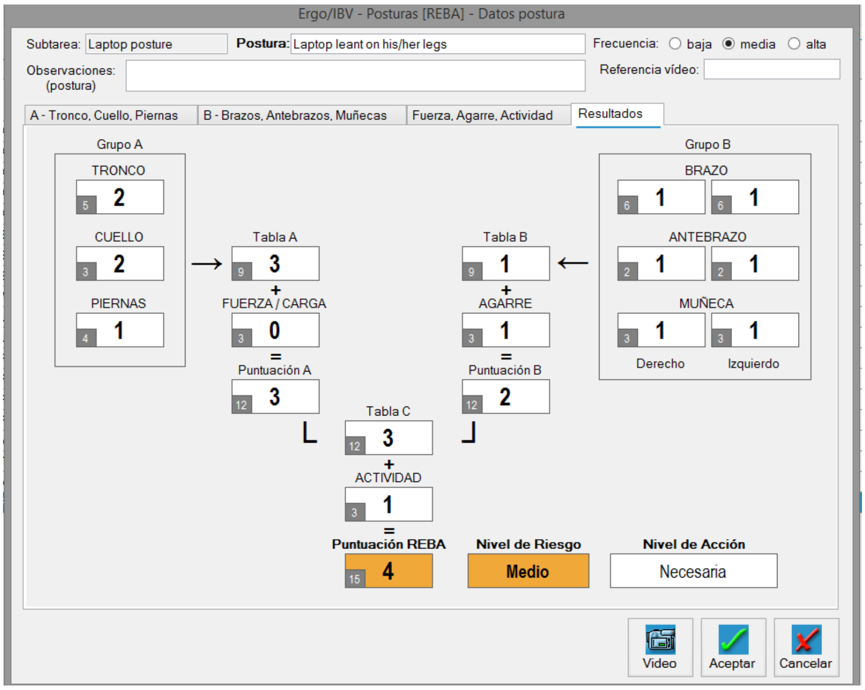

Figure 74. *Screen shot of ERGO/IBV REBA scores in Laptop posture (laptop leant on the passenger's legs).*

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(f) iPad posture

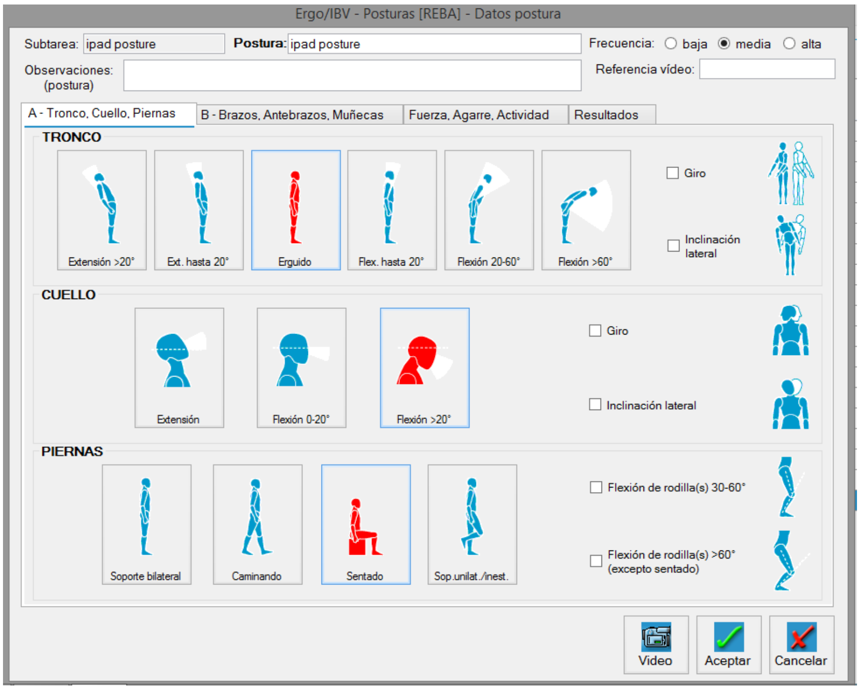

Figure 75. *Screen shot of trunk, neck and legs body segment angle definition in iPad posture.*

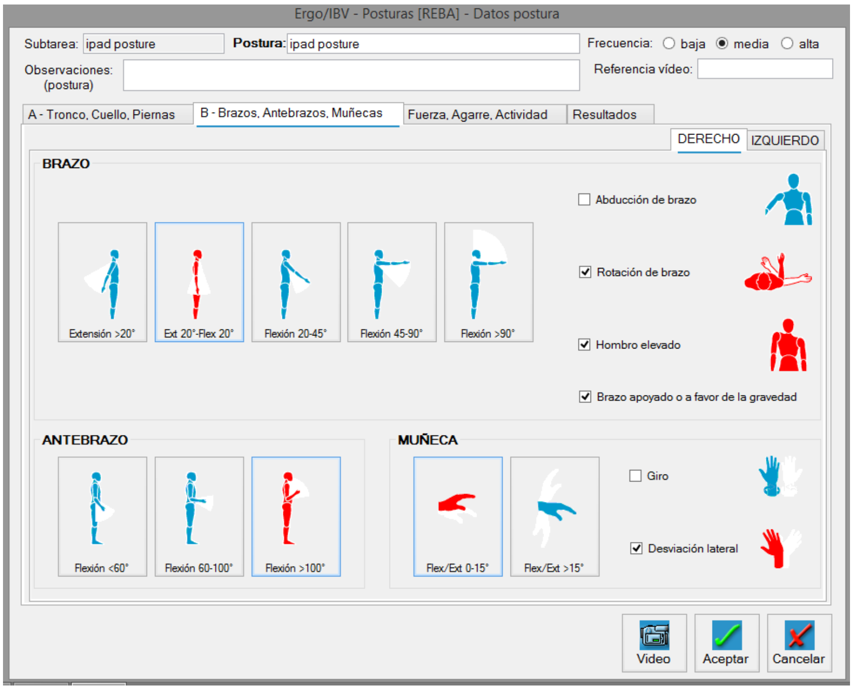

Figure 76. *Screen shot of right arm, forearm and wrist body segment angle definition in iPad posture.*

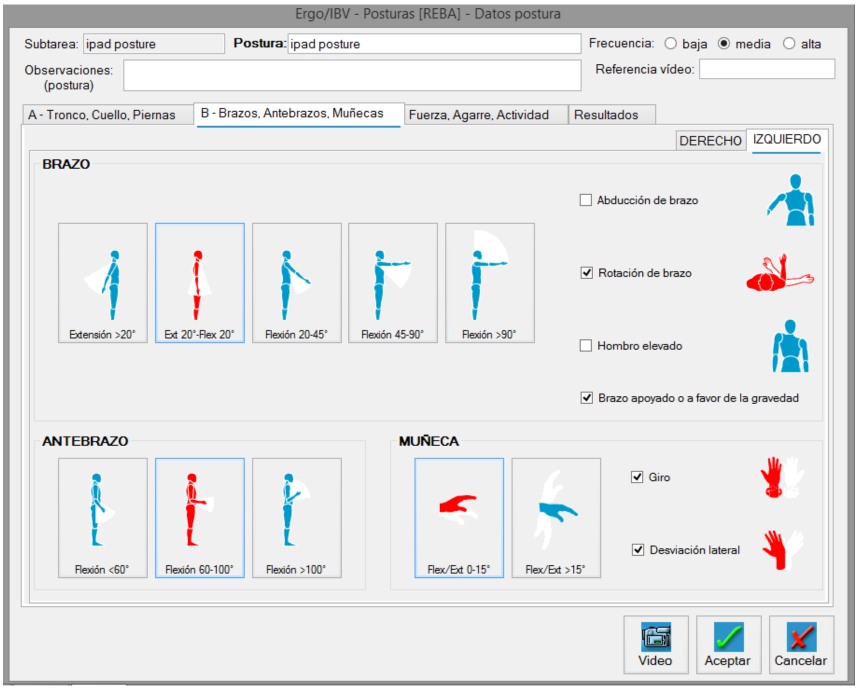

Figure 77. *Screen shot of left arm, forearm and wrist body segment angle definition in iPad posture.*

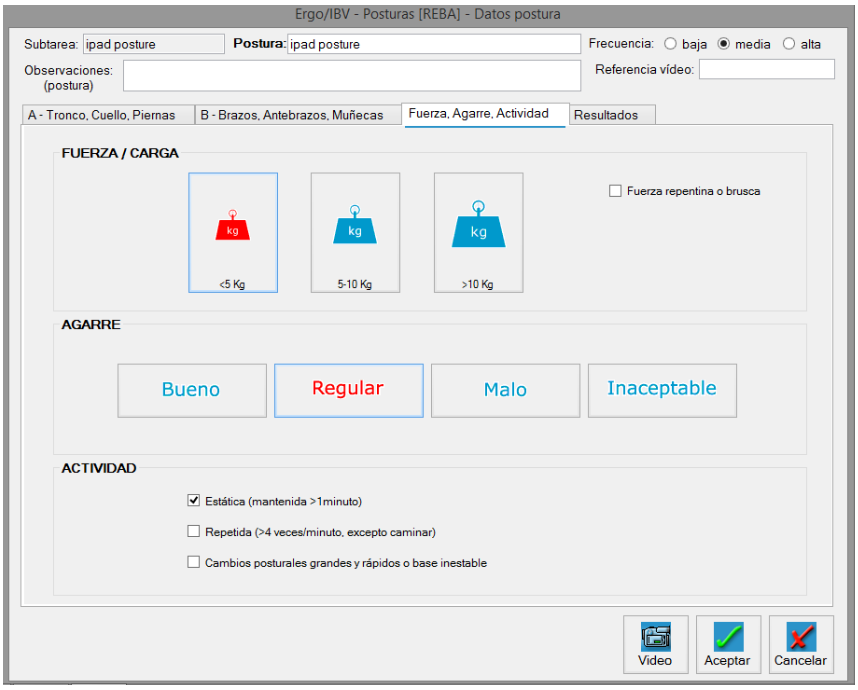

Figure 78. *Screen shot of load, type of grip and activity definition in iPad posture.*

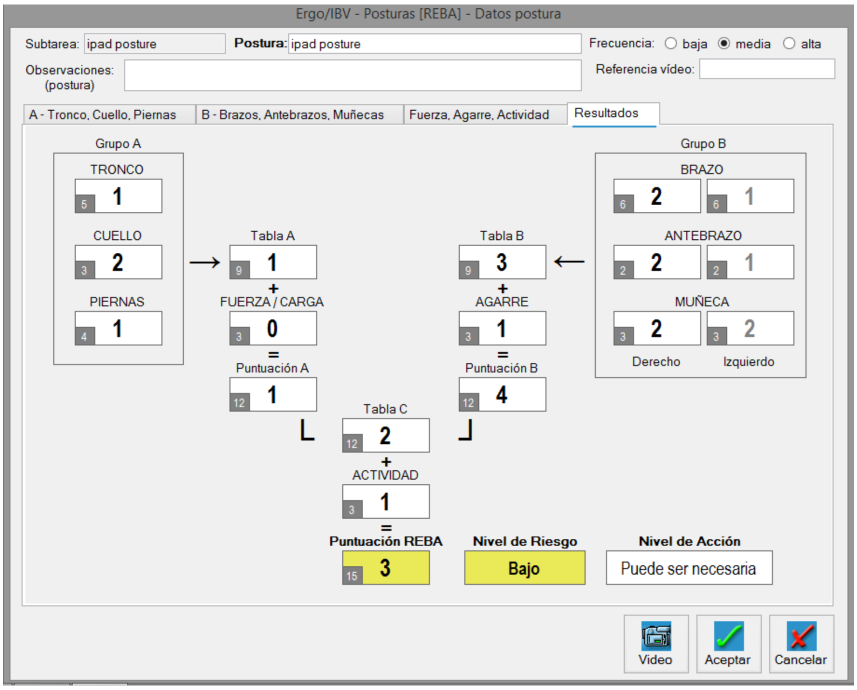

Figure 79. *Screen shot of ERGO/IBV REBA scores in iPad posture.*

(g) Reading position (with flexed arms at the shoulder joint)

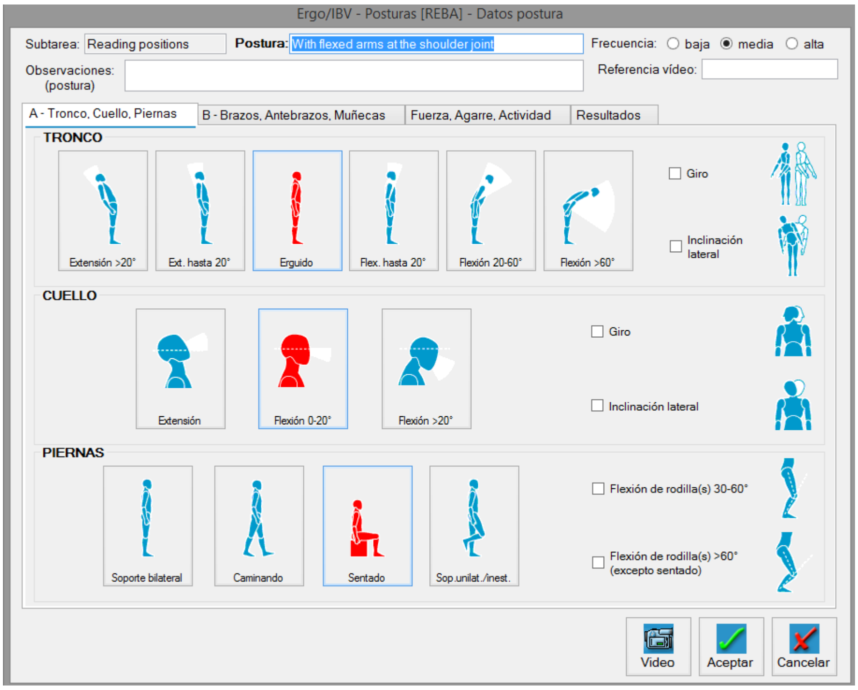

Figure 80. *Screen shot of trunk, neck and legs body segment angle definition in Reading position (with flexed arms at the shoulder joint).*

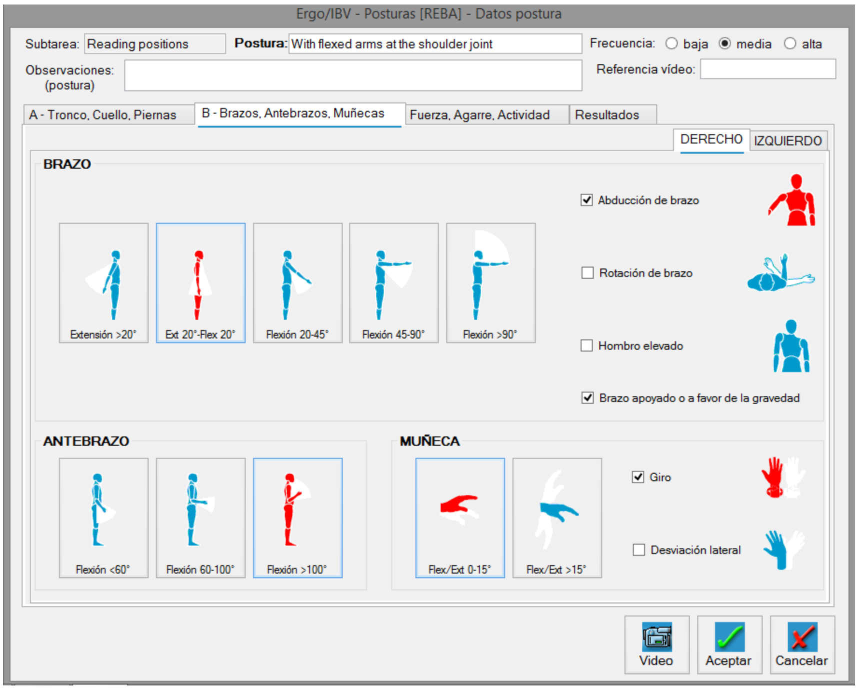

Figure 81. *Screen shot of right/left arm, forearm and wrist body segment angle definition in Reading position (with flexed arms at the shoulder joint).*

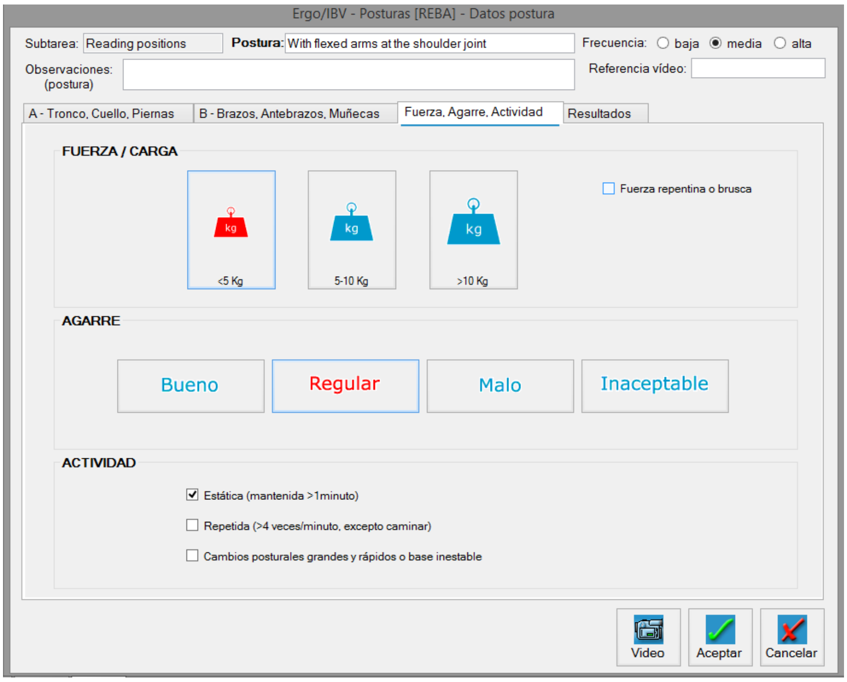

Figure 82. *Screen shot of load, type of grip and activity definition in Reading position (with flexed arms at the shoulder joint).*

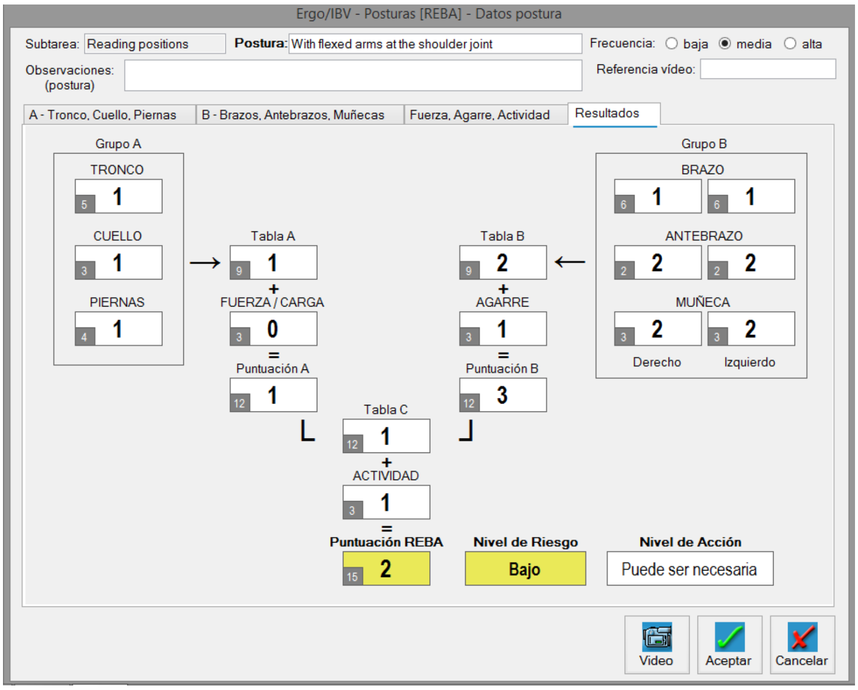

Figure 83. *Screen shot of ERGO/IBV REBA scores in Reading position (with flexed arms at the shoulder joint).*

(h) Reading position (supporting the arm that holds the book)

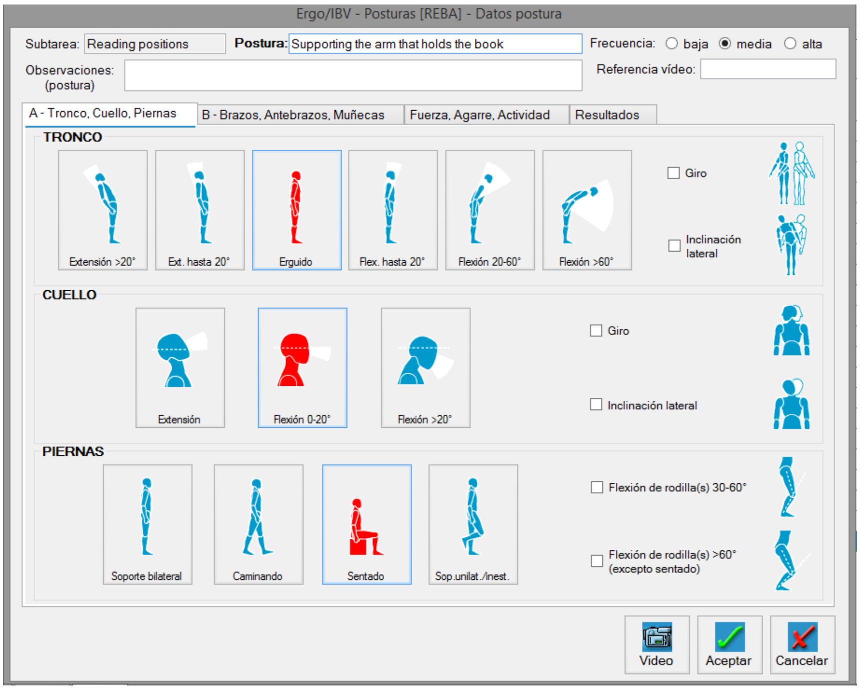

Figure 84. *Screen shot of trunk, neck and legs body segment angle definition in Reading position (supporting the arm that holds the book).*

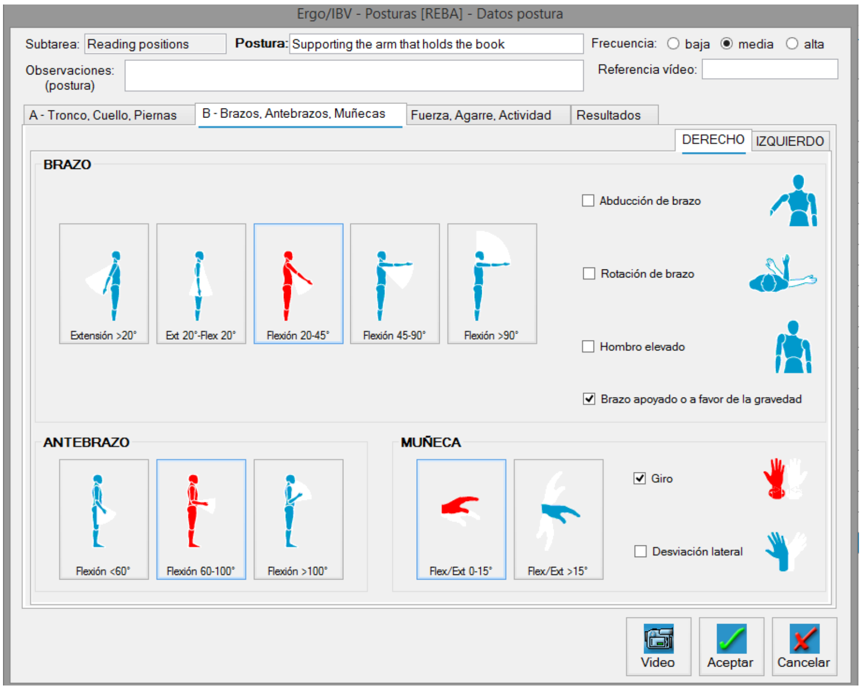

Figure 85. *Screen shot of right arm, forearm and wrist body segment angle definition in Reading position (supporting the arm that holds the book).*

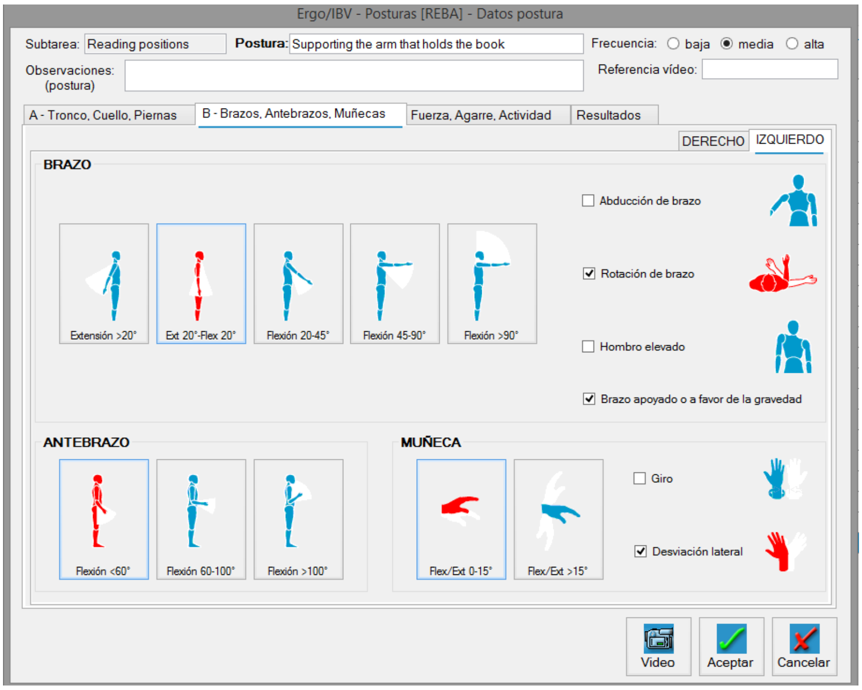

Figure 86. *Screen shot of left arm, forearm and wrist body segment angle definition in Reading position (supporting the arm that holds the book).*

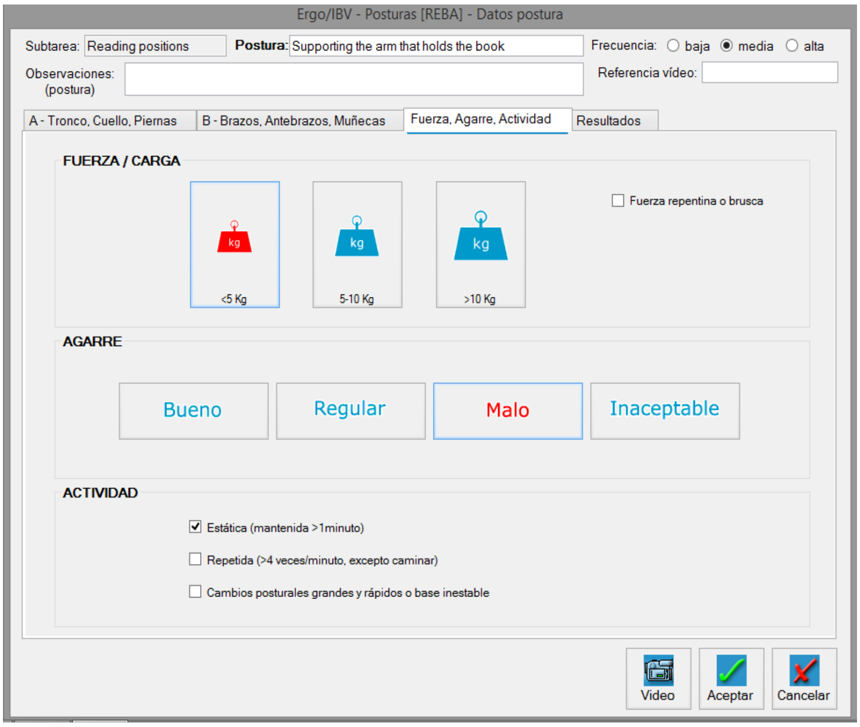

Figure 87. *Screen shot of load, type of grip and activity definition in Reading position (supporting the arm that holds the book).*

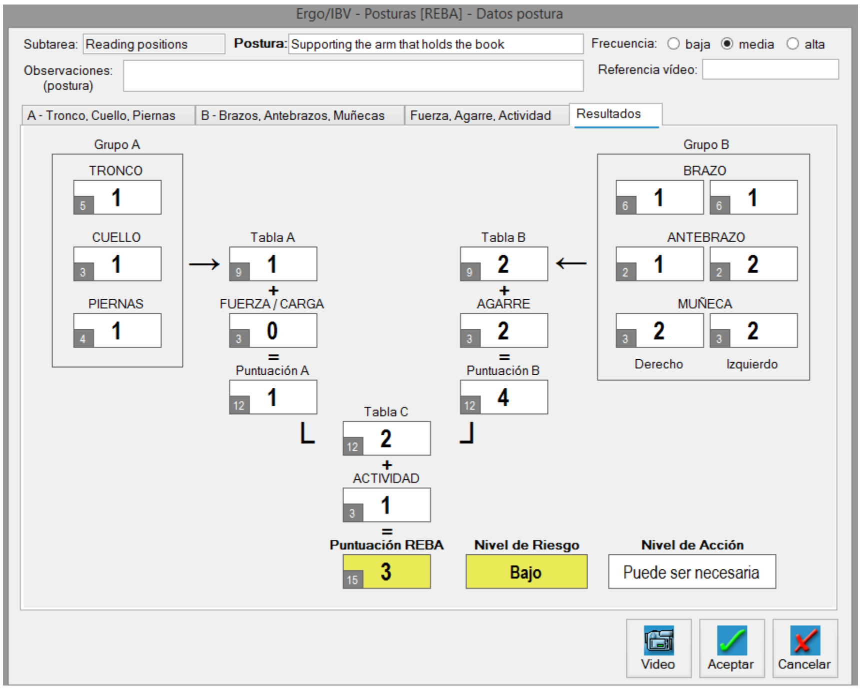

Figure 88. *Screen shot of ERGO/IBV REBA scores in Reading position (supporting the arm that holds the book).*

(i) Sleeping posture – Neutral position (a)

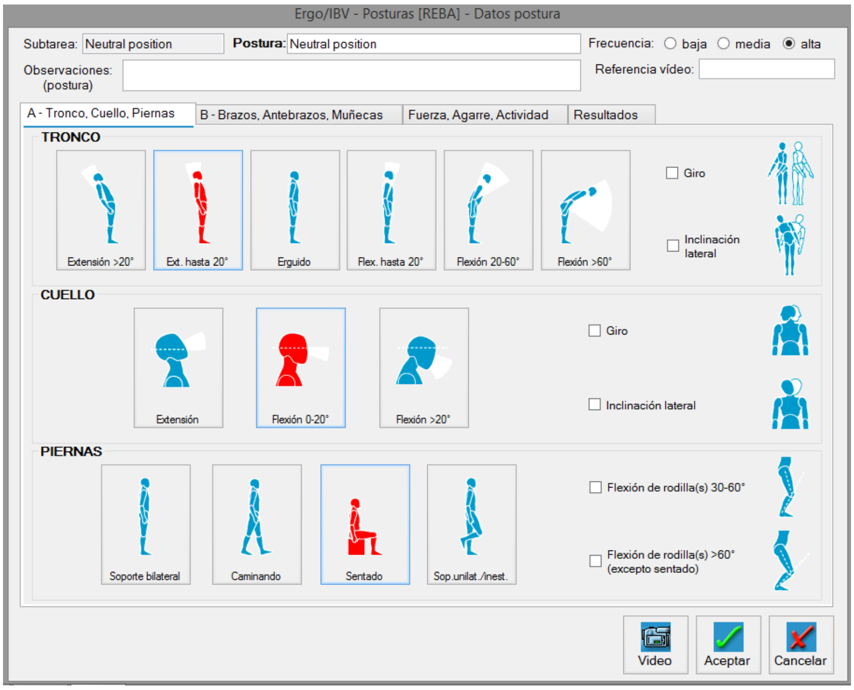

Figure 89. *Screen shot of trunk, neck and legs body segment angle definition in Sleeping posture (neutral position).*

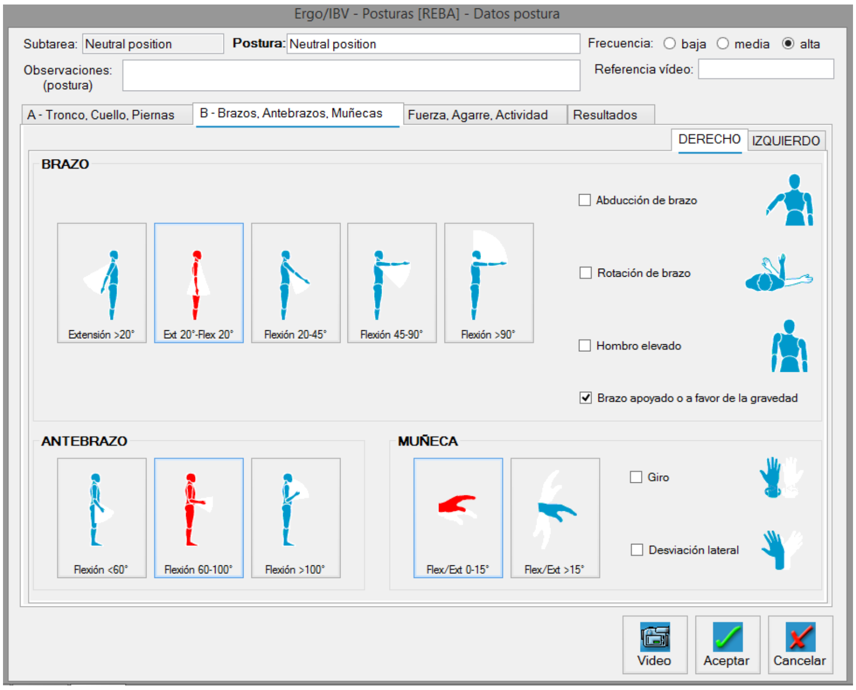

Figure 90. *Screen shot of right/left arm, forearm and wrist body segment angle definition in Sleeping posture (neutral position).*

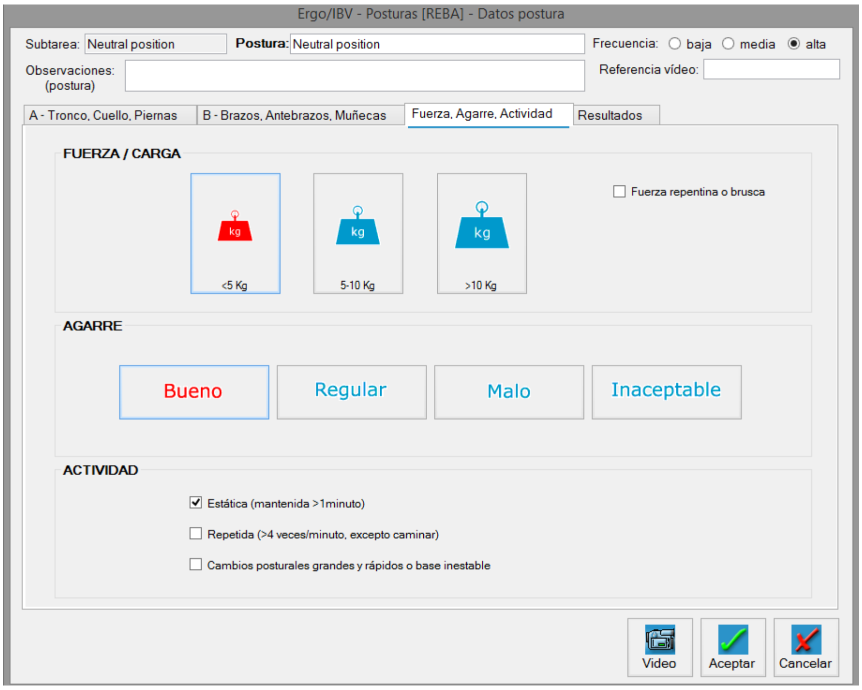

Figure 91. *Screen shot of load, type of grip and activity definition in Sleeping posture (neutral position).*

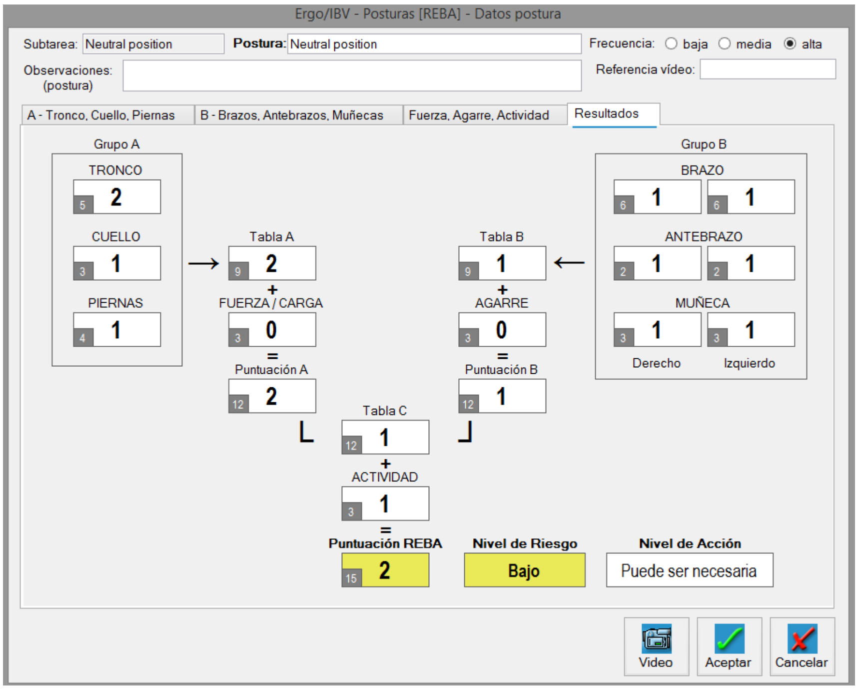

Figure 92. *Screen shot of ERGO/IBV REBA scores in Sleeping posture (neutral position).*

(j) Sleeping posture – Slide down (b) y (c)

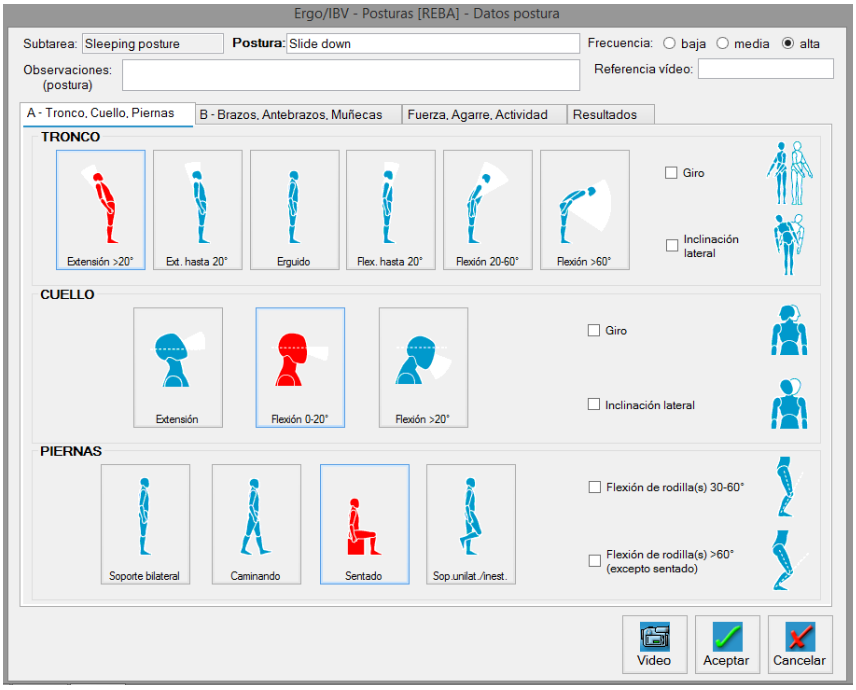

Figure 93. *Screen shot of trunk, neck and legs body segment angle definition in Sleeping posture (slide down).*

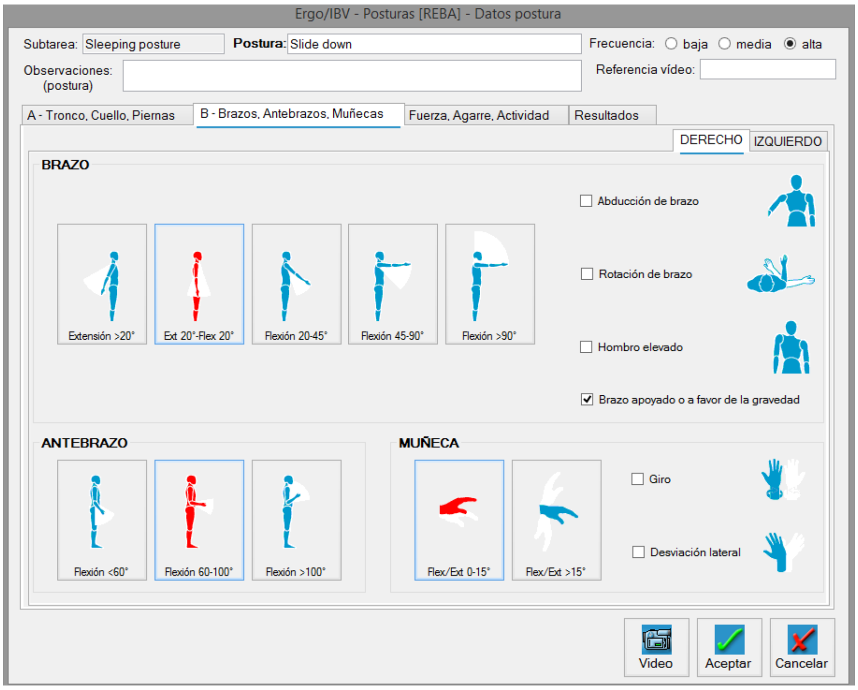

Figure 94. *Screen shot of right/left arm, forearm and wrist body segment angle definition in Sleeping posture (slide down).*

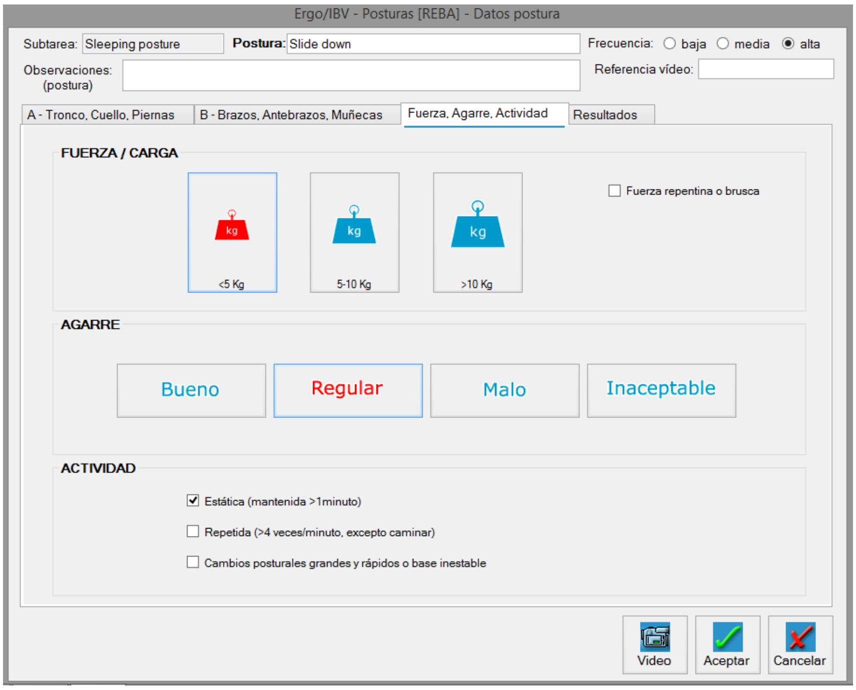

Figure 95. *Screen shot of load, type of grip and activity definition in Sleeping posture (slide down).*

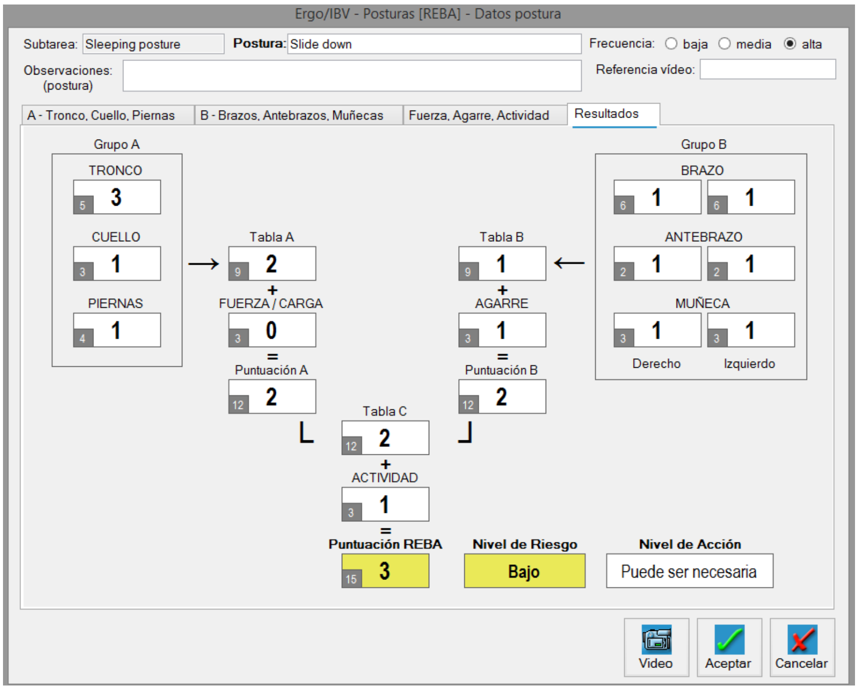

Figure 96. *Screen shot of ERGO/IBV REBA scores in Sleeping posture (slide down).*

(k) Sleeping posture – Sideway position (d), (e), (f) y (g)

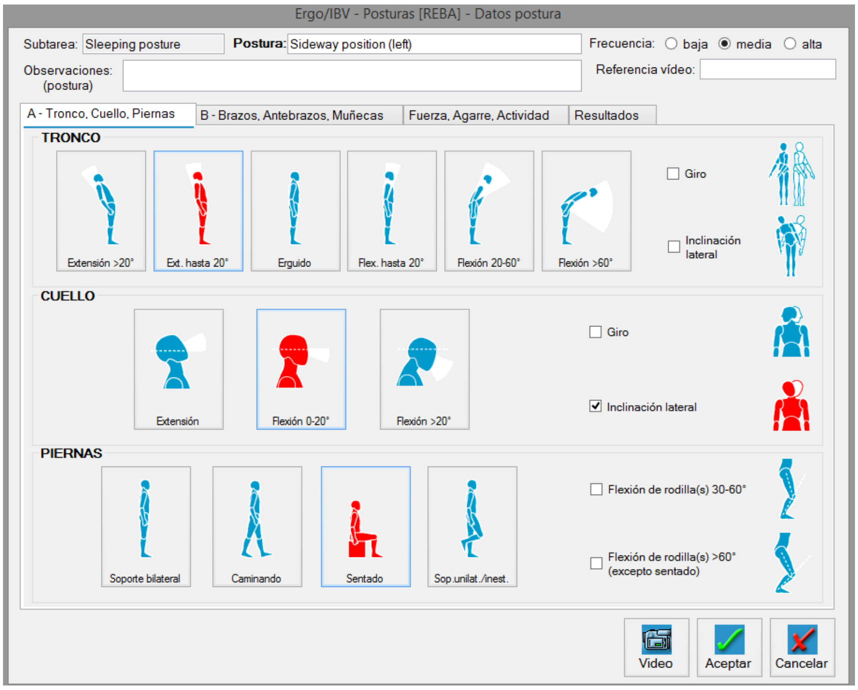

Figure 97. *Screen shot of trunk, neck and legs body segment angle definition in Sleeping posture (sideway position).*

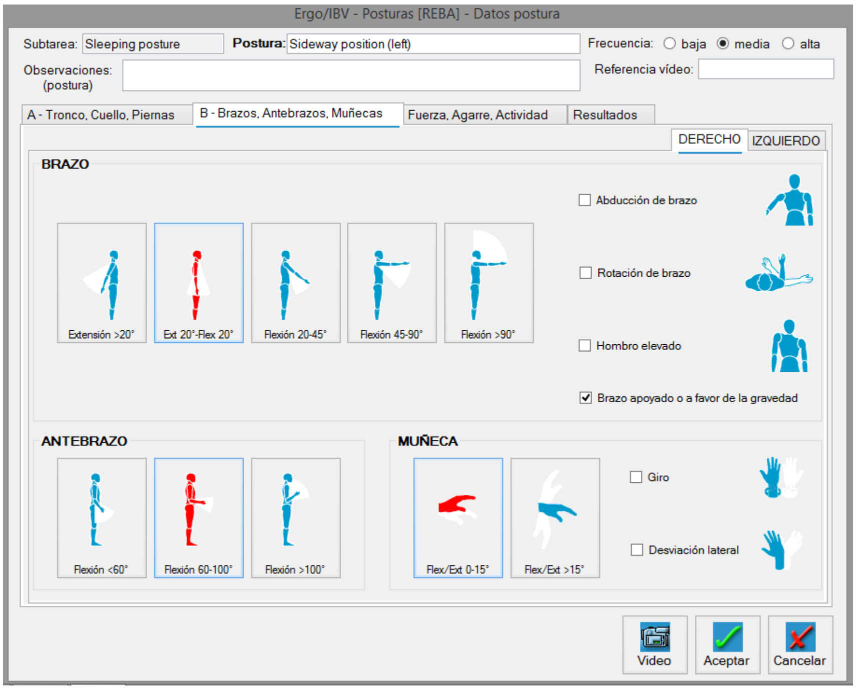

Figure 98. *Screen shot of right/left arm, forearm and wrist body segment angle definition in Sleeping posture (sideway position).*

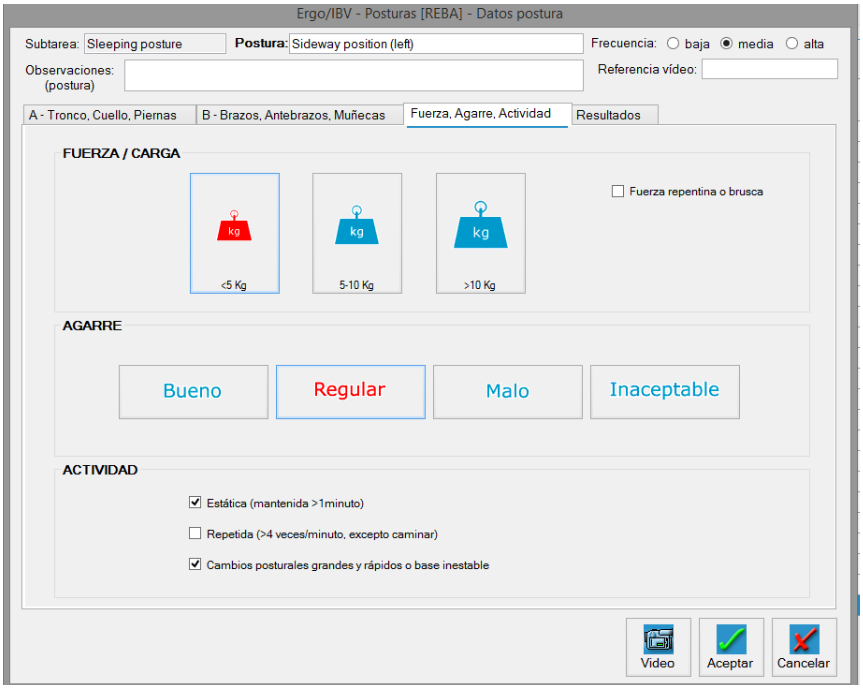

Figure 99. *Screen shot of load, type of grip and activity definition in Sleeping posture (sideway position).*

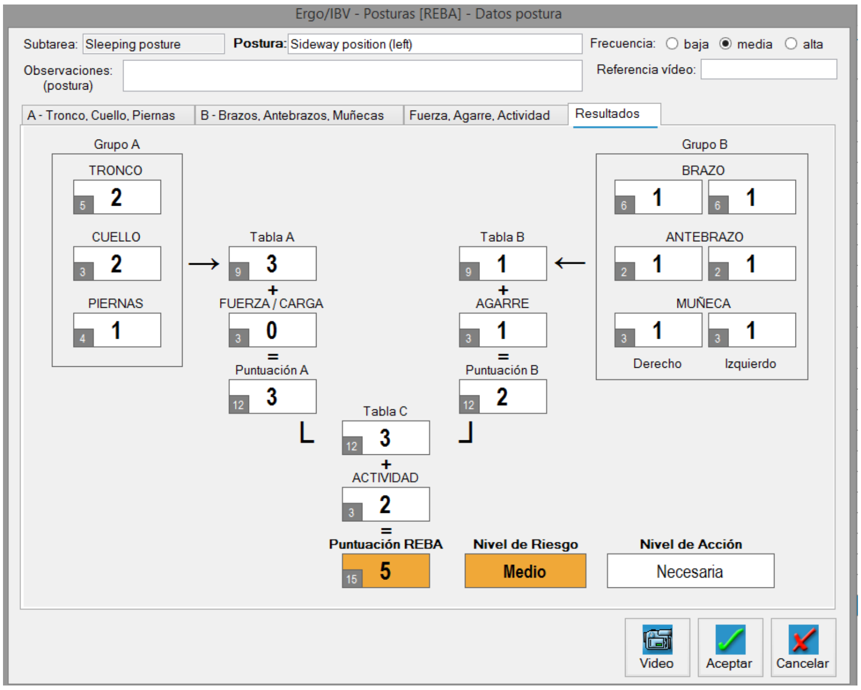

Figure 100. *Screen shot of ERGO/IBV REBA scores in Sleeping posture (sideway position).*

(I) Sleeping posture – Sideway position (with hands) (h) y (i)

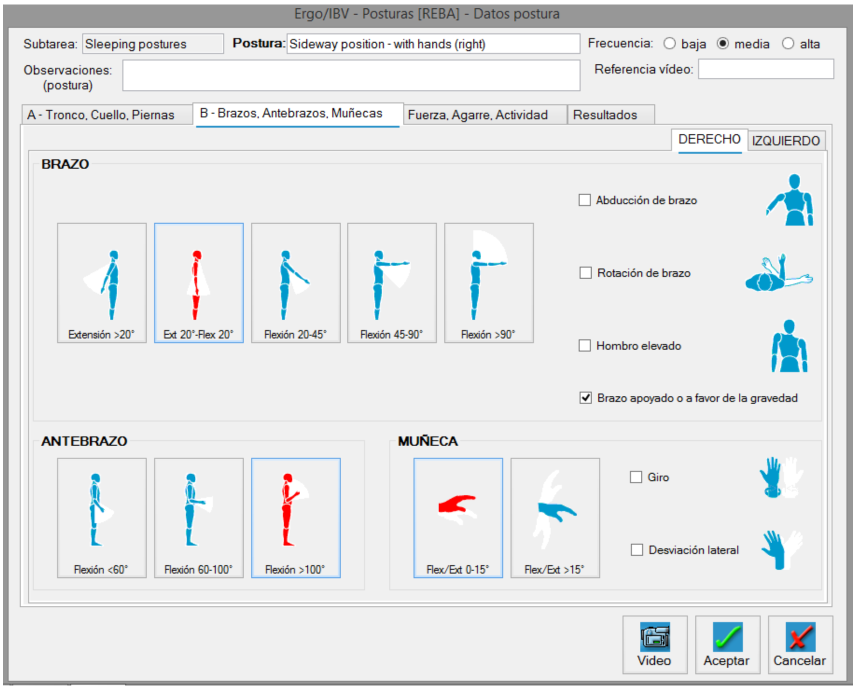

Figure 101. *Screen shot of trunk, neck and legs body segment angle definition in Sleeping posture (sideway position – with hands).*

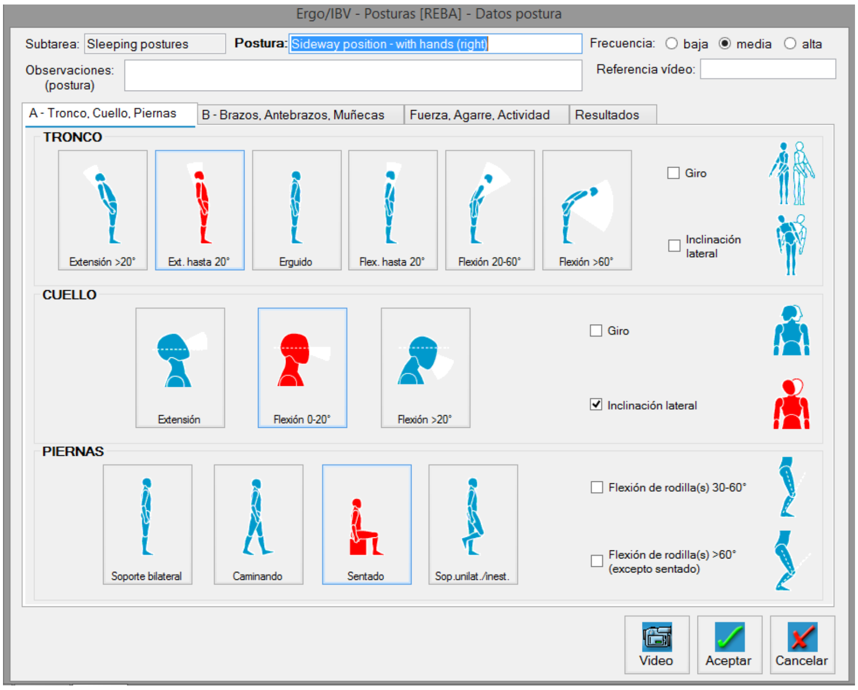

Figure 102. *Screen shot of right arm, forearm and wrist body segment angle definition in Sleeping posture (sideway position – with hands).*

Figure 103. *Screen shot of left arm, forearm and wrist body segment angle definition in Sleeping posture (sideway position – with hands).*

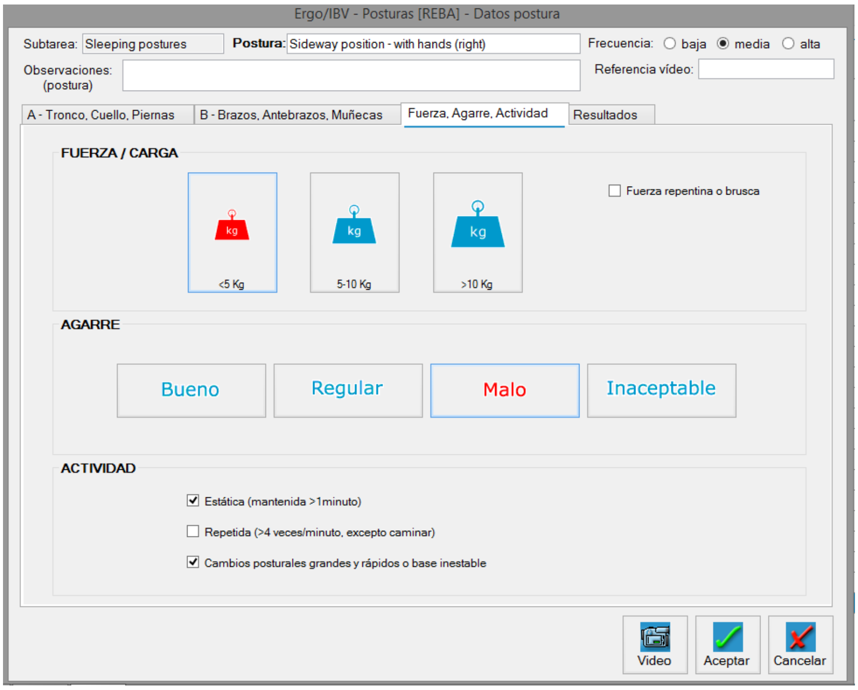

Figure 104. *Screen shot of load, type of grip and activity definition in Sleeping posture (sideway position – with hands).*

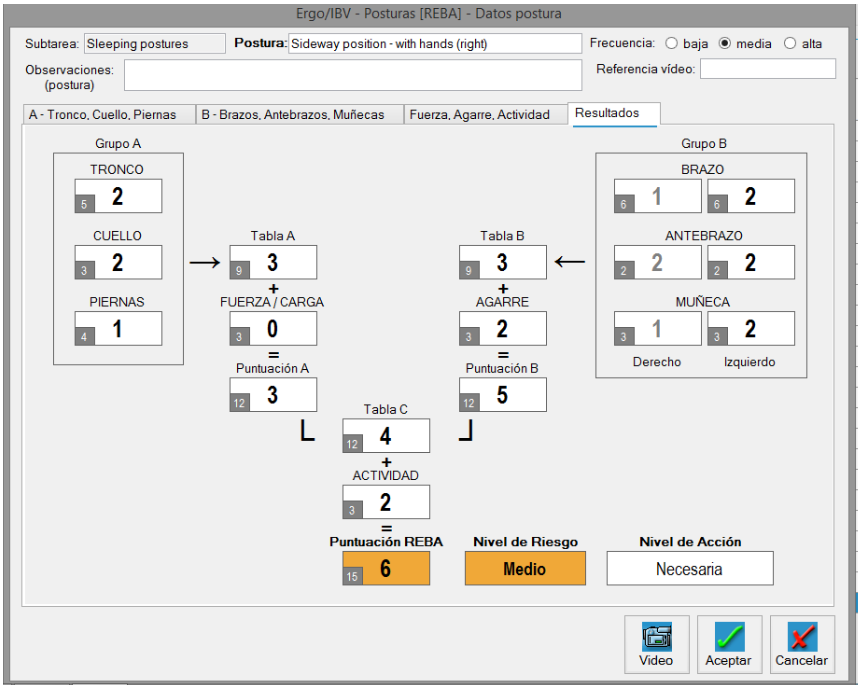

Figure 105. *Screen shot of ERGO/IBV REBA scores in Sleeping posture (sideway position – with hands).*

(m) Sleeping posture – Turned torso (j), (k), (l) y (m)

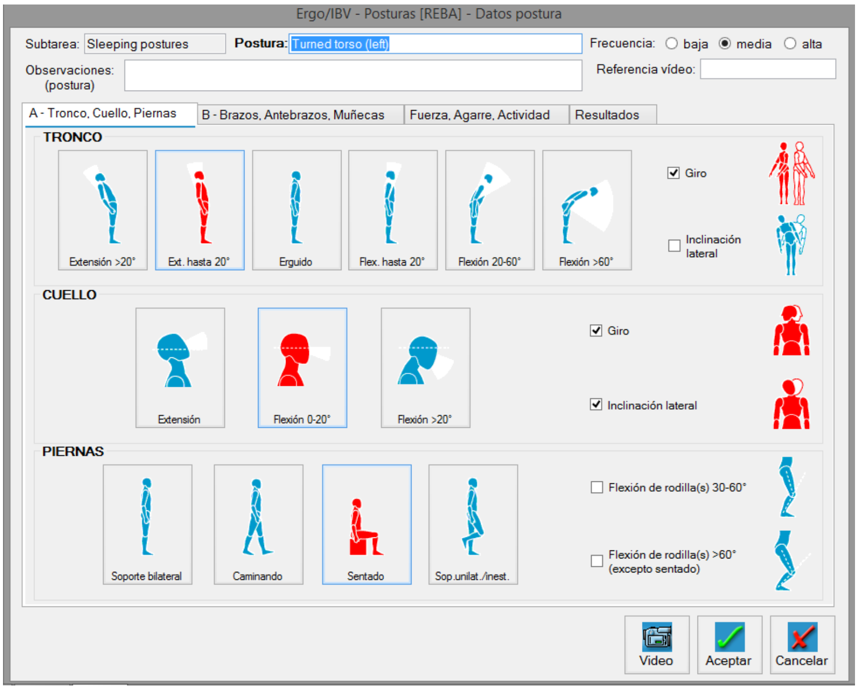

Figure 106. *Screen shot of trunk, neck and legs body segment angle definition in Sleeping posture (turned torso).*

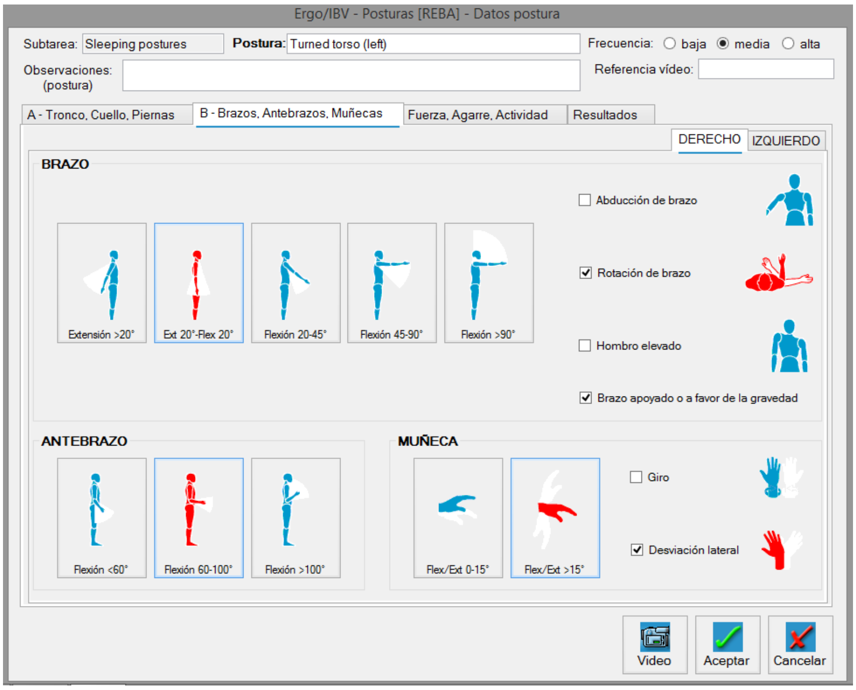

Figure 107. *Screen shot of right arm, forearm and wrist body segment angle definition in Sleeping posture (turned torso).*

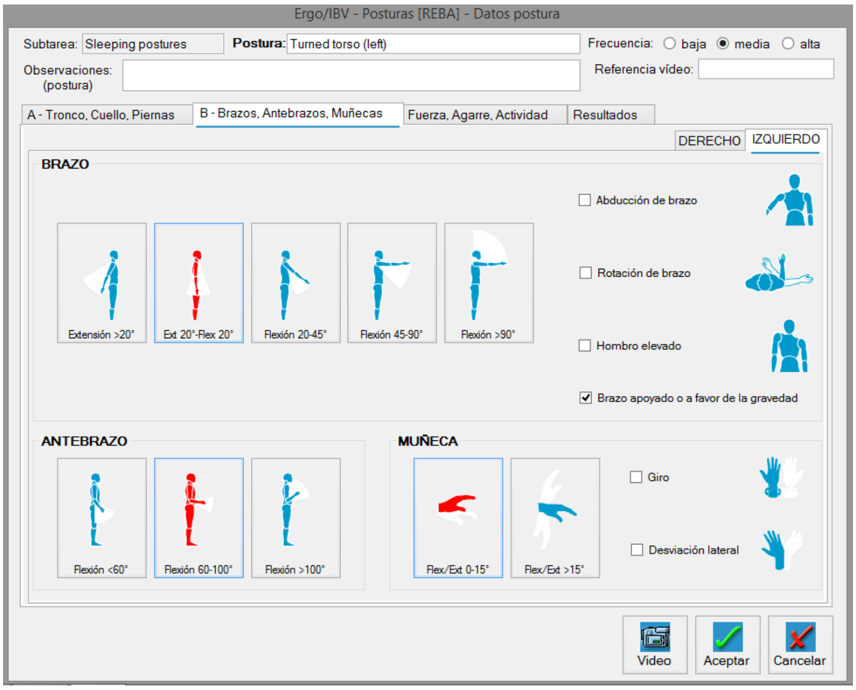

Figure 108. *Screen shot of left arm, forearm and wrist body segment angle definition in Sleeping posture (turned torso).*

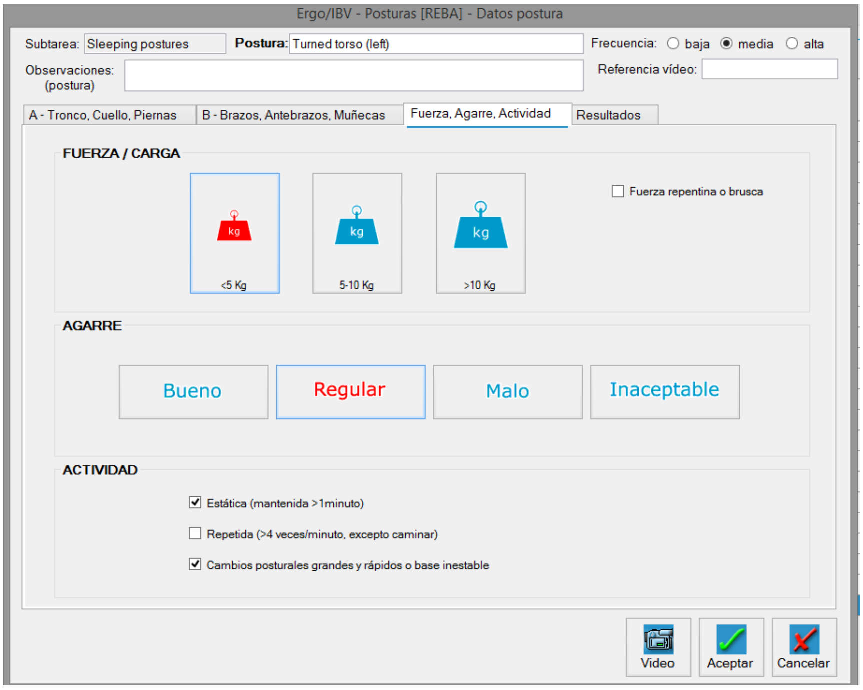

Figure 109. *Screen shot of load, type of grip and activity definition in Sleeping posture (turned torso).*

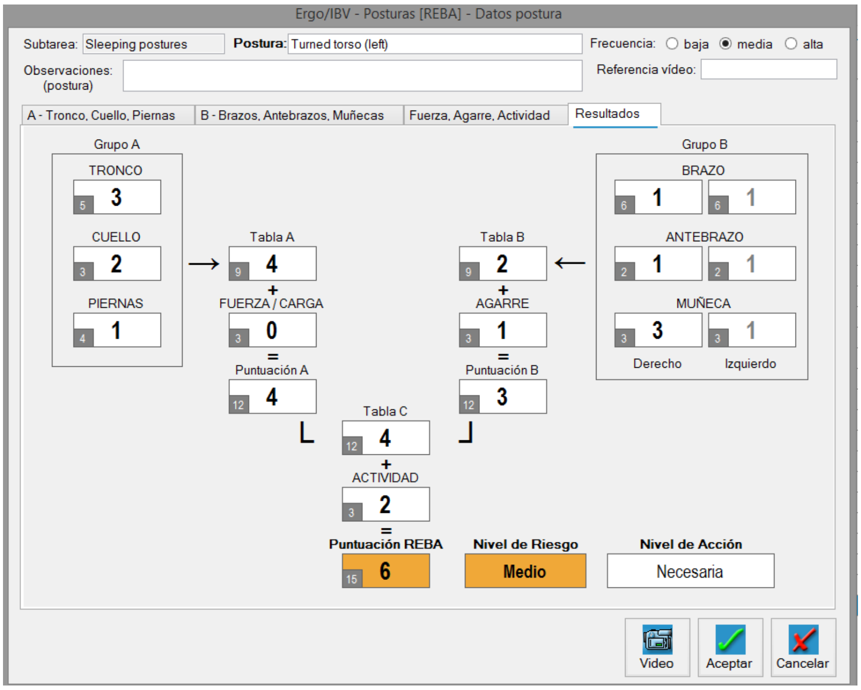

Figure 110. *Screen shot of ERGO/IBV REBA scores in Sleeping posture (turned torso).*

(n) Sleeping posture – Turned torso (head perpendicular to back rest) (n) y (o)

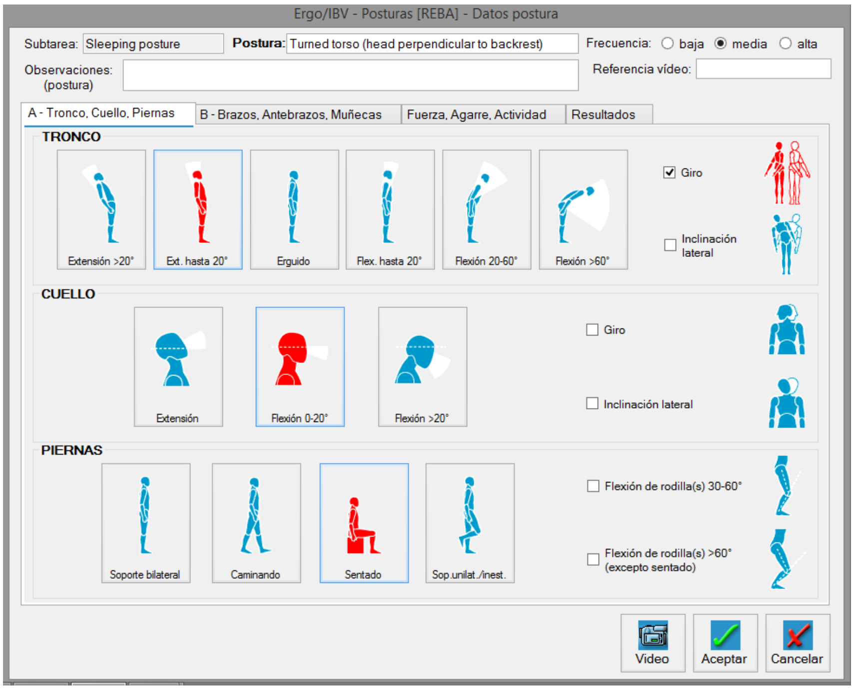

Figure 111. *Screen shot of trunk, neck and legs body segment angle definition in Sleeping posture (turned torso – head perpendicular to back rest).*

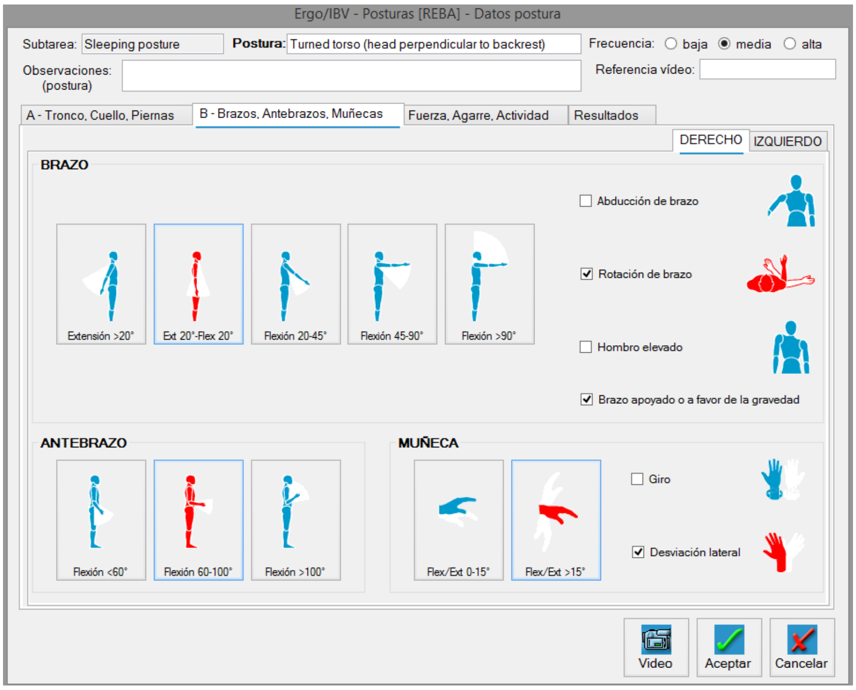

Figure 112. *Screen shot of right arm, forearm and wrist body segment angle definition in Sleeping posture (turned torso – head perpendicular to back rest).*

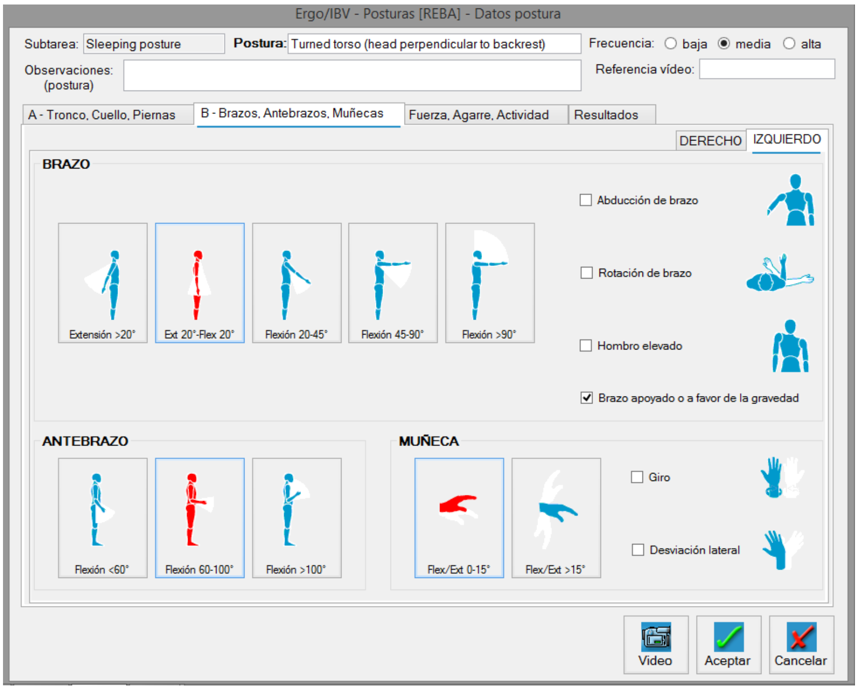

Figure 113. *Screen shot of left arm, forearm and wrist body segment angle definition in Sleeping posture (turned torso – head perpendicular to back rest).*

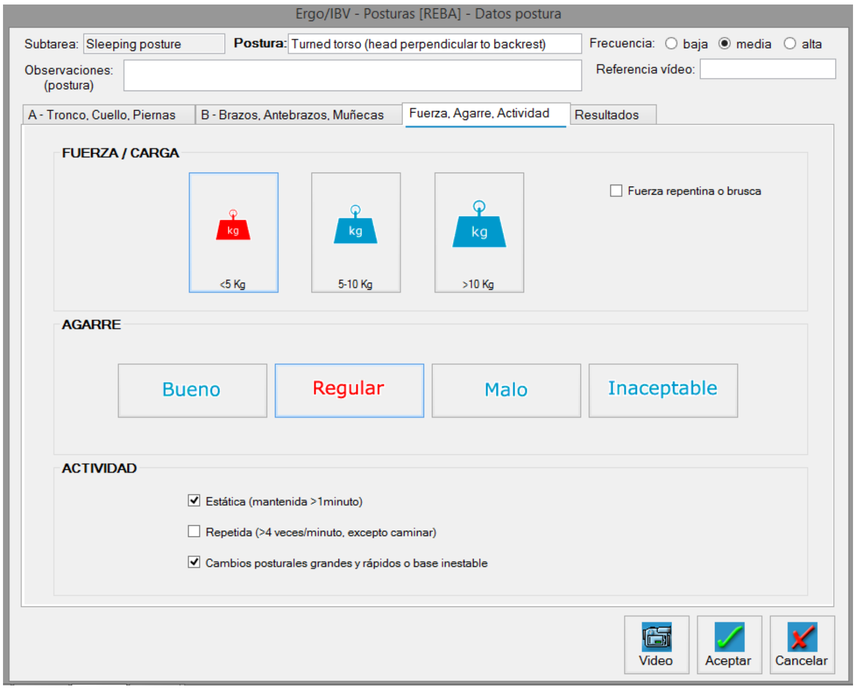

Figure 114. *Screen shot of load, type of grip and activity definition in Sleeping posture (turned torso – head perpendicular to back rest).*

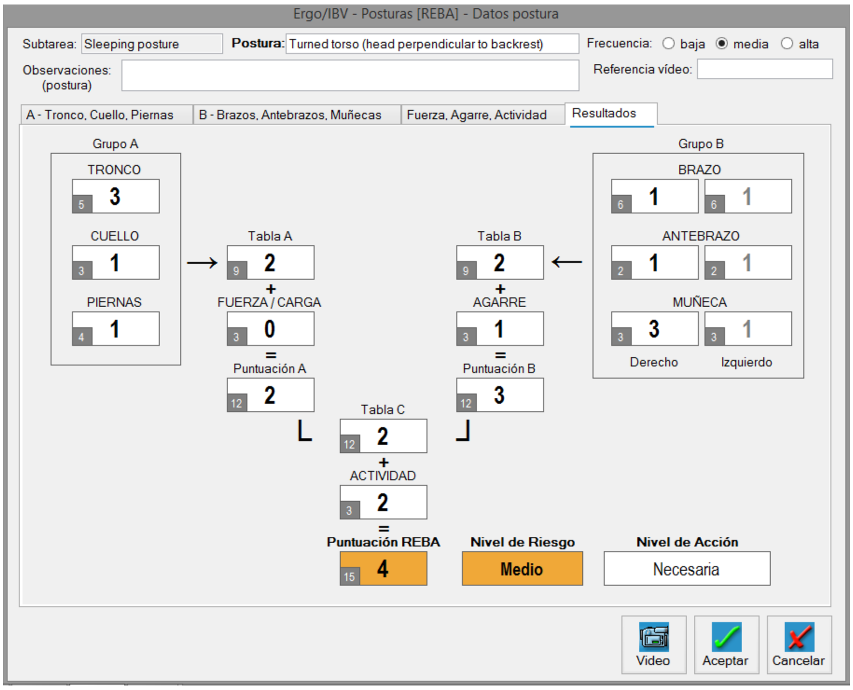

Figure 115. *Screen shot of ERGO/IBV REBA scores in Sleeping posture (turned torso – head perpendicular to back rest).*

(o) Baby posture

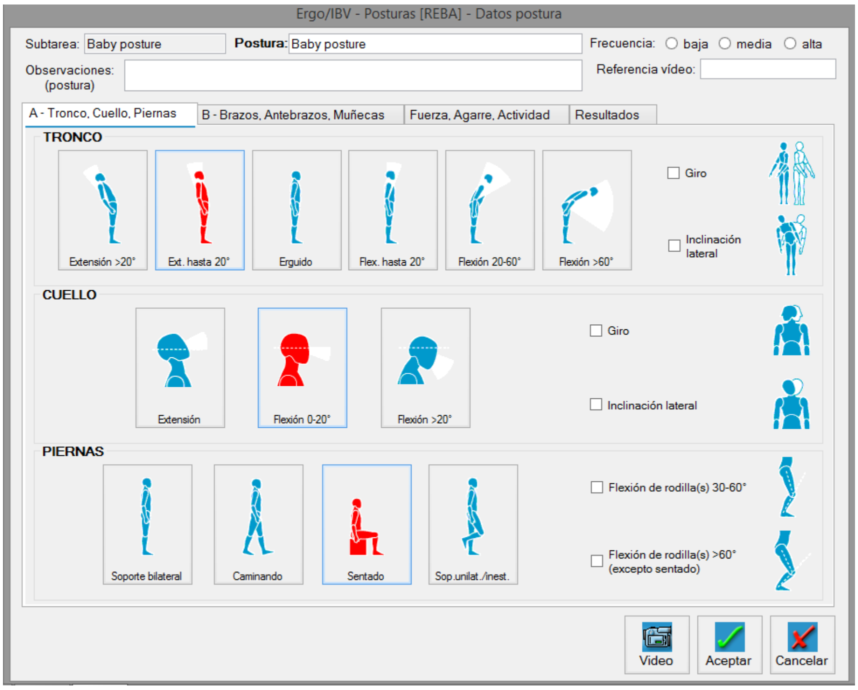

Figure 116. *Screen shot of trunk, neck and legs body segment angle definition in Baby posture.*

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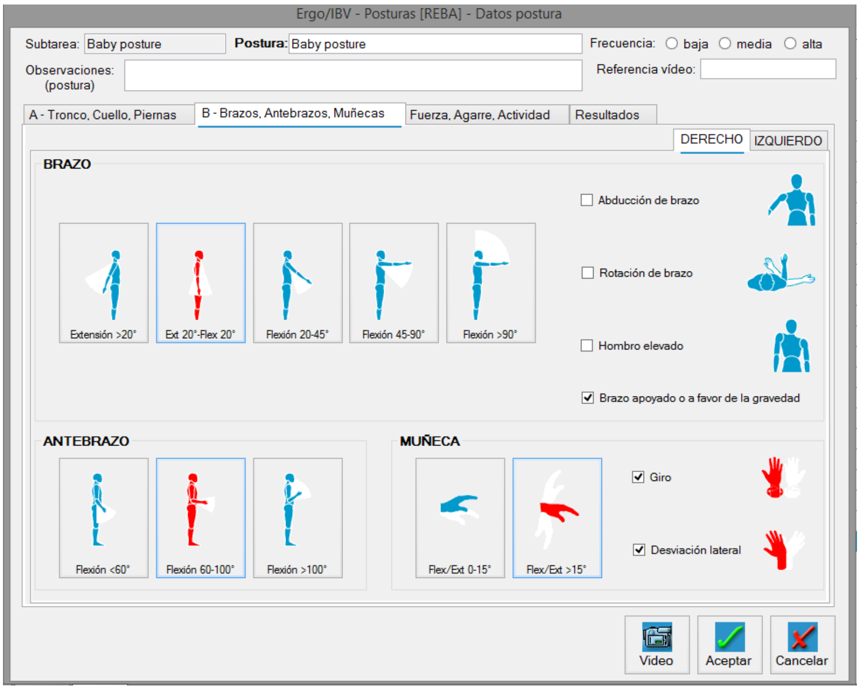

Figure 117. *Screen shot of left arm, forearm and wrist body segment angle definition in Baby posture.*

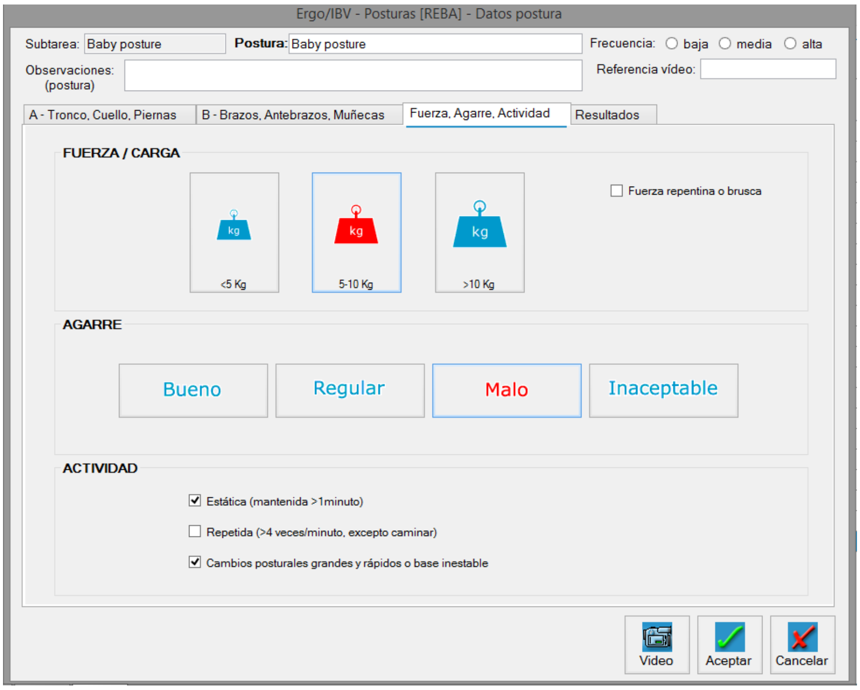

Figure 118. *Screen shot of load, type of grip and activity definition in Baby posture.*

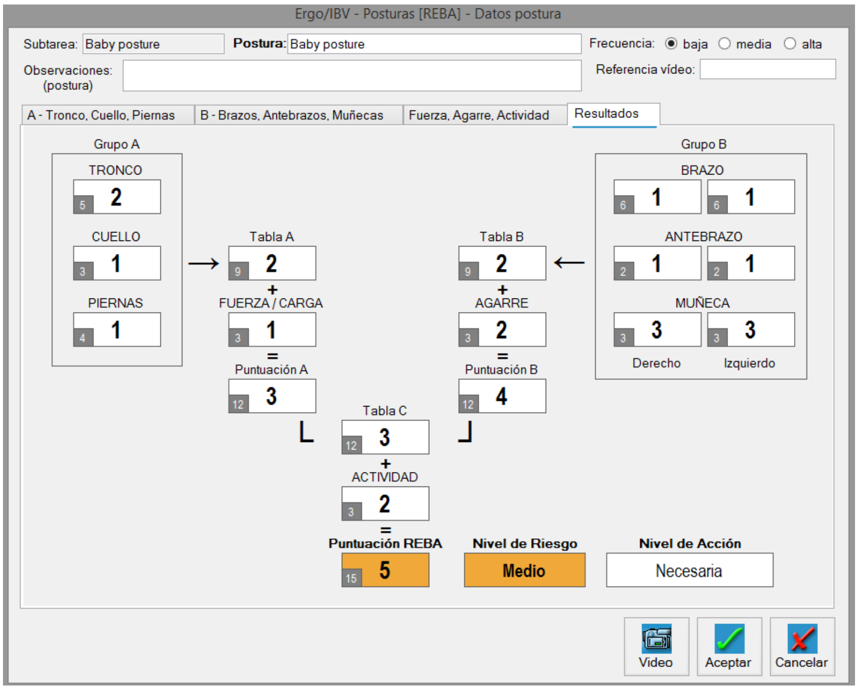

Figure 119. *Screen shot of ERGO/IBV REBA scores in Baby posture.*

(p) Eating posture

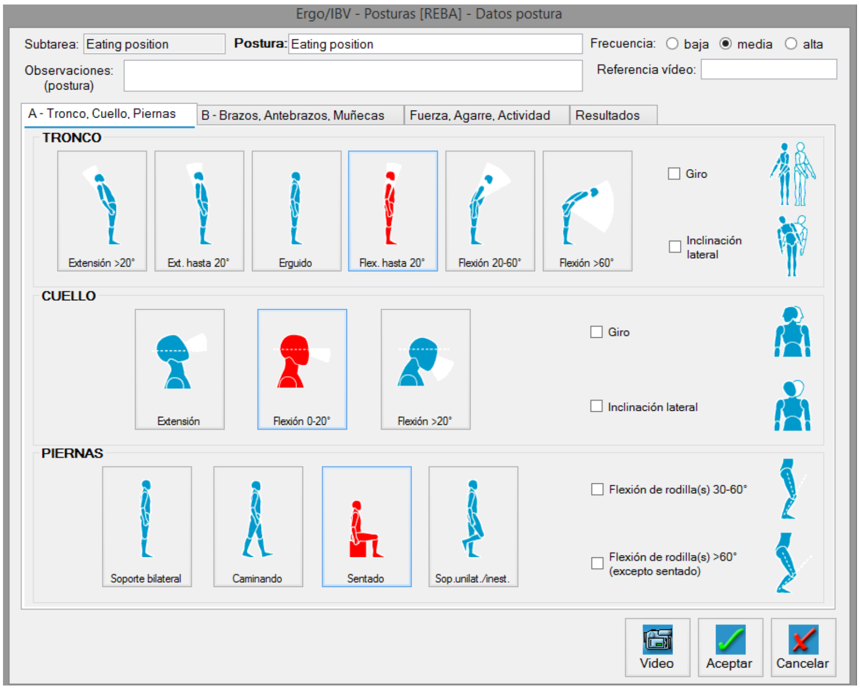

Figure 120. *Screen shot of trunk, neck and legs body segment angle definition in Eating posture.*

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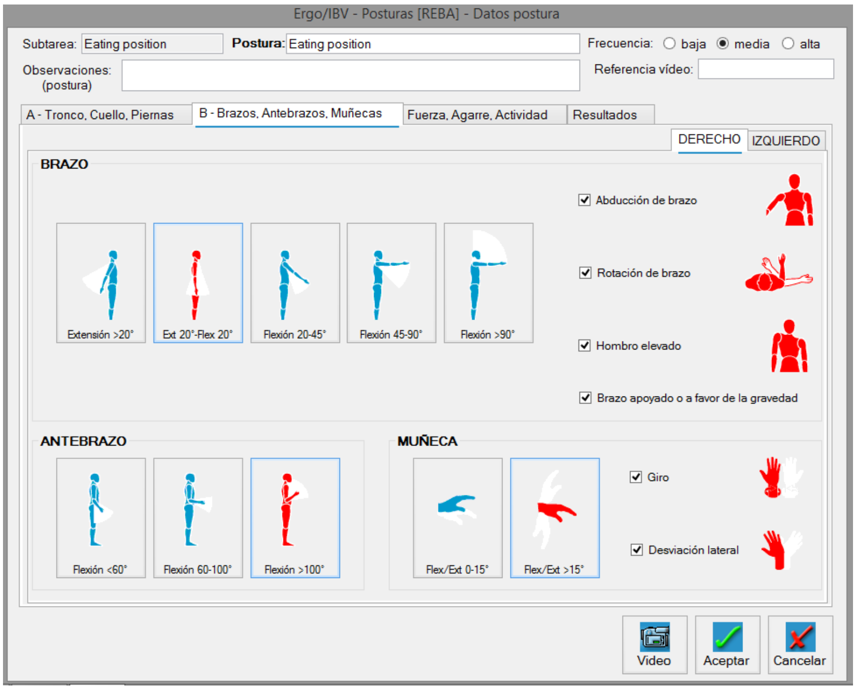

Figure 121. *Screen shot of right arm, forearm and wrist body segment angle definition in Eating posture.*

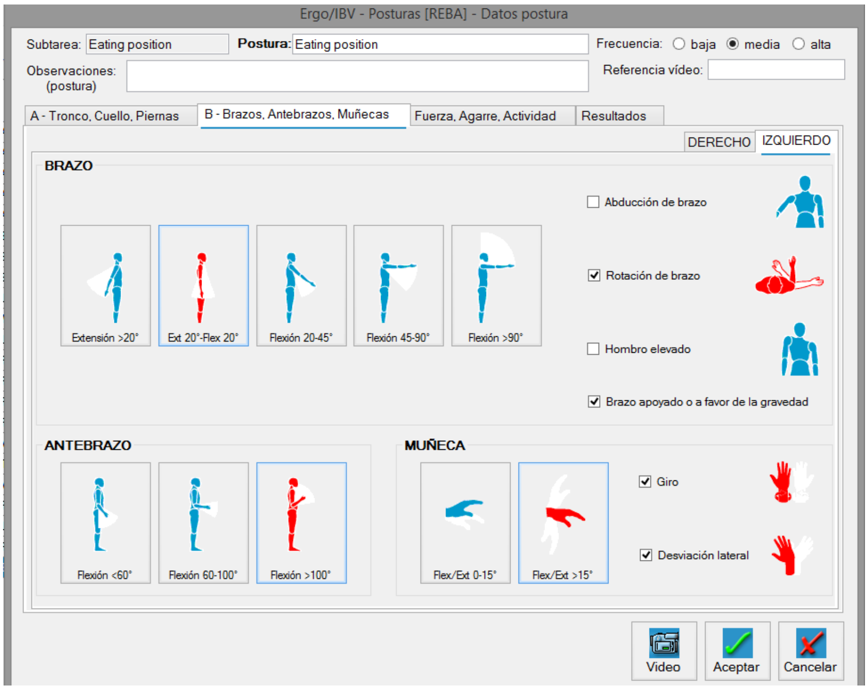

Figure 122. *Screen shot of left arm, forearm and wrist body segment angle definition in Eating posture.*

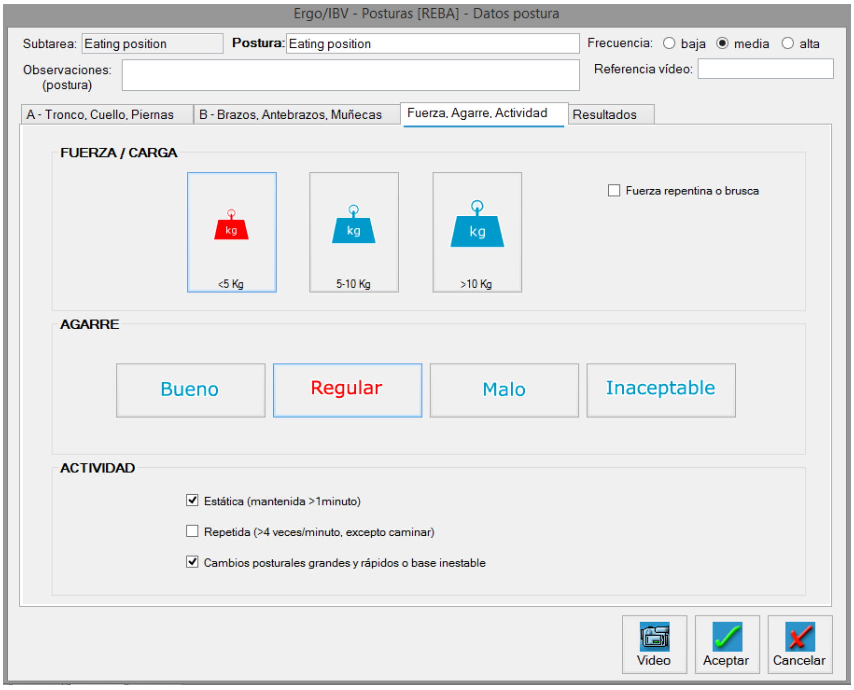

Figure 123. *Screen shot of load, type of grip and activity definition in Eating posture.*

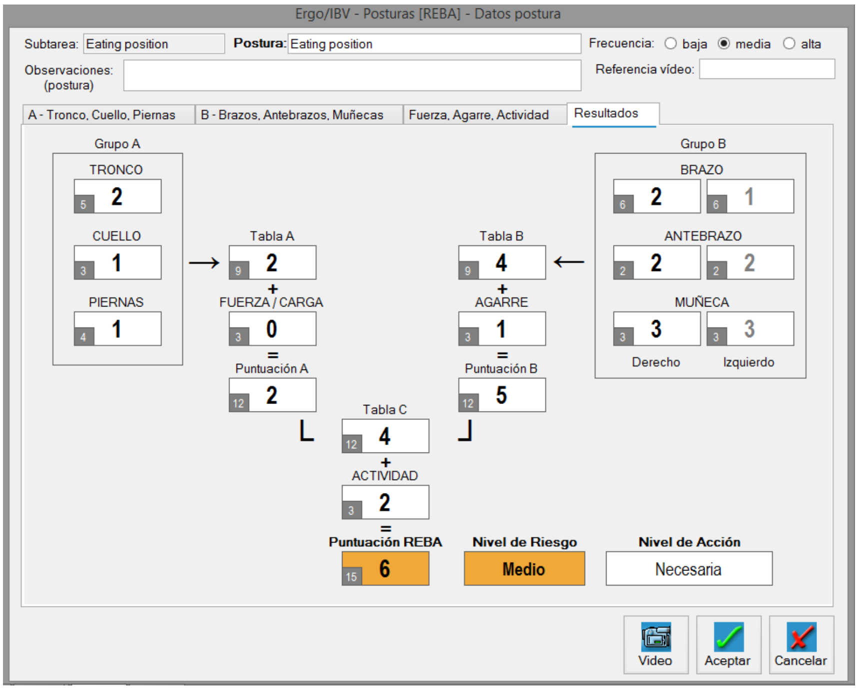

Figure 124. *Screen shot of ERGO/IBV REBA scores in Eating posture.*